The Effects of Linear Developments on Wildlife: A Review of Selected Scientific Literature

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The Effects of Linear Developments on Wildlife: A Review of Selected Scientific Literature
Executive Summary

Arc Wildlife Services Ltd. was contracted by the Canadian Association of Petroleum Producers, the Alberta Energy and Utilities Board, and Nova Corporation to conduct a review of the scientific literature describing the effects of linear developments on wildlife, especially large mammals. Of particular interest were the types of roads and linear developments created by the oil and pipeline industries in western Canada.

The effects of linear developments on wildlife are best understood in the context of regional and landscape ecology: the spatial arrangement of ecological processes on the land. The land we live on can be considered a *mosaic,* a pattern of objects on the land that can be divided into three basic units: patches, corridors, and matrices. A *patch* is a reasonably homogenous non-linear area that differs from its surroundings. Similarly, *corridors* may be defined in general as reasonably similar linear areas that differ from their surroundings. Finally, a *matrix* is the background ecosystem, or land-use type in the mosaic. Using these broad definitions, a patch could be anything from a well site to a marsh. Roads, seismic lines, and hedgerows are examples of corridors, and a matrix could be a forest, a prairie, a rural subdivision, or a farming area. This examination of the effects of linear developments on wildlife will focus on the effects of *disturbance corridors* like roads and powerline rights-of-way since they are more commonly encountered in oil and gas activities. However, *remnant corridors*, long, narrow strips of original habitat in an otherwise disturbance-dominated landscape (e.g., roadside verges in an agricultural landscape or forest strips in a logged forest environment), are also important to wildlife and are discussed where appropriate.

Scale is an important concept within the study of landscapes. A *landscape* is a kilometres-wide mosaic of ecosystems. Within a landscape, there is a recurring pattern of patches, corridors and matrices. The matrix and the type and configuration of patches and corridors on that matrix determine the viability of the landscape for different species of wildlife. Wildlife species that are sensitive to human disturbance and that have large area requirements (e.g., grizzly bear) are more likely to be affected by linear developments than widespread species that require less space (e.g., snowshoe hare), since the former are more likely to encounter a development within their home areas . However, species which are not widespread within a landscape and are dependent on particular landscape elements for their survival (e.g., long-toed salamander and ponds) may also be significantly affected by a linear development if the development removes or affects a critical landscape element.

Development corridors may affect wildlife in a wide variety of ways. The range of effects of any particular corridor is in part a function of the corridor itself. Corridors have both internal and external structure. *Internal structure* characteristics can be grouped into

3 categories: width characteristics, internal entities, and plant and animal community structure. Width characteristics include the environmental gradient across a corridor (i.e., moving from adjacent habitat across the edge to the interior of the corridor and back across to the edge to the opposite bordering habitat), edge characteristics (e.g., abrupt vs. uneven), and the effects of different habitats on either side of the corridor. The portion of a corridor, patch, or matrix near its perimeter is referred to as an edge. Corridors have a high edge-to-area ratio because they are, by definition, long and thin. The edge effect refers to the high population density and diversity of wildlife that typically occurs along edges. Internal entities refer to structures like roads or ditches within a right-of-way clearing.

External structure is a corridor's structure in the surrounding matrix and includes a wide variety of factors such as a corridor's relationship to its surroundings (e.g., corridor length, patchiness, distribution of attached nodes, adjoining patches or matrix), curvilinearity and width (variability in width, distribution of narrows) and connectivity and gaps (gap sizes, gap frequency, habitat suitability in and around gaps). Connectivity refers to the degree to which an ecosystem is connected or joined together. For forest-dwelling wildlife living in landscapes divided by disturbance corridors, the degree of connectivity is inversely related to the number of disturbance corridors that divide the landscape into disjointed pieces. Landscapes with high connectivity typically have few disturbance corridors. Once again corridor structure is important. Connectivity decreases with increased width of the right-of-way. Connectivity will be best across forest trails and will be progressively worse as right-of-way width increases. Divided highways may be complete barriers to movement for some species. Increased curvilinearity in a disturbance corridor probably increases connectivity between bordering habitats since sight lines are shorter; winding roads through forested habitat affect connectivity less than long, straight seismic lines.

Corridors function in 5 different ways for wildlife; they act as habitat, conduits, filters or barriers, sources, and sinks. Corridors are considered *habitat* when they provide wildlife with some requisites for survival such as food or shelter (e.g., grazing habitat for ungulates). A corridor is a *conduit* when wildlife moves along it (e.g., a wolf traveling along a packed seismic line in winter). Corridors may be *filters* or *barriers* when wildlife movements across or along them are hindered or blocked (e.g., roads with high traffic volumes). Corridors may be *sources* if wildlife living in the corridor spreads out into the surrounding habitat (e.g., mice) or they may be *sinks* if wildlife is attracted to the corridor and die as a result (roads and wildlife-vehicle collisions). Corridor structure plays a major role in determining the extent to which a corridor fulfills each of the 5 functions.

The effects of development corridors on wildlife can be subdivided into 6 major categories: individual disruption, social disruption, habitat avoidance, habitat disruption or enhancement, direct and indirect mortality, and populations effects. The presence or absence of any particular effect is dependent on the species of wildlife and the structure of the corridor. The disturbance corridor itself or activities associated with the corridor often disturb wildlife resulting in wildlife leaving the corridor area or altering patterns of use, responses that carry with them costs in terms of energy expenditure and possibly lost opportunities (*individual disruption*). Disturbance corridors and activities associated with them may lead to wildlife avoiding habitats close to the corridors (*habitat avoidance*). Habitat in the vicinity of the corridor is effectively lost. Fragmentation of the landscape may occur if avoidance of disturbance corridors prevents wildlife from fully using land on either side of a corridor. *Social disruption* refers to any changes to the social structure of a population as a result of the disturbance corridor. This disturbance may take several forms such as the displacement of wildlife from the corridor into adjacent habitats that are already occupied by other individuals of the same species, changes in group structure for gregarious species, or differential mortality of classes as a result of the disturbance corridor. Disturbance corridors may remove or provide additional habitat for wildlife. Examples of *habitat disruption* include the construction of all types of road or entire road rights-of-way if they are fenced. *Habitats may be enhanced* for wildlife if new habitat features are created along corridors that were not present prior to the construction of the corridor. New habitat may be beneficial to wildlife residing in the surrounding habitat or it may provide opportunities for new wildlife species to colonize an area. Activities associated with disturbance corridors may result in mortalities. Examples of *direct sources of mortality* are wildlife-vehicle collisions or powerline strikes and electrocutions. Disturbance corridors may also be important contributors to *indirect mortality*. Indirect mortality is typically associated with human access. Human access generally leads to additional mortality due to hunting, trapping, poaching, and management actions. Predators such as wolves may benefit from the presence of the disturbance corridor in a similar way. Behavioural responses to disturbance may lead to *population effects,* typically a reduction in the population. Population effects don't necessarily follow even from significant behavioural responses. Conversely, it is possible that population effects may occur even though no behavioural response to a disturbance was detected. To confirm the presence of a population effect, the demographics of the population must be studied.

Of all disturbance corridors humans create, *roads* probably have the greatest impact on wildlife populations. The most important effects are direct and indirect mortality and the loss of habitat effectiveness as a result of habitat avoidance in the vicinity of disturbance corridors. The effects of *trails, pipelines, and seismic lines* on wildlife are similar in nature to those of roads. However, effects tend to be less significant for these smaller corridors since their physical attributes are less disruptive (e.g., narrower rights-of-way, increased curvilinearity of trails) and fewer people are associated them. The effects of *railways* and railway rights-of-way are different and likely less disruptive to wildlife than roads, although studies of their effects on wildlife beyond direct mortality are few. Human activity on the railway right-of-way is minimal relative to roads, pipelines, and seismic lines. In addition, disturbance is predictable and generally does not involve humans outside of the train, further reducing the likelihood of significant disturbances. However, if wildlife use of the railway results in increased levels of habituation to humans, then the effects will be more detrimental. Grain spillage from rail cars is an example of this. Bears, both grizzlies and blacks, are attracted to this food source. In addition to increased risks of mortality due to collisions with trains, bears attracted to the railway right-of-way are more likely to be less wary in the vicinity of humans in other situations and thereby increase the likelihood that they will die from human-related causes.

Individual disruption occurs in the vicinity of disturbance corridors for all wildlife species. The corridor itself typically does not cause a disturbance response; it's the human presence on it that causes problems. Certain species of large mammals like grizzly bears, wolverines, and elk tend to be more sensitive to disturbance than others like bighorn sheep, mountain goats, or marten. Closed roads are generally not avoided by wildlife. On roads open to traffic, vehicles that never stop may be ignored in some cases, even among more sensitive species. However, stopped vehicles and people leaving their vehicles cause increased levels of disruption. Typically, hunted wildlife populations exhibit stronger disturbance reactions to people along roads than does wildlife in protected areas. The experience of individuals appears to have a great effect on the degree of disturbance. Within a national park, elk in the backcountry exhibited greater levels of disruption when confronted by humans than elk residing in the immediate presence of people. Grizzly bears are known to avoid open roads in general, yet in protected populations some bears become habituated to the point that they will use roadside verges with apparent disregard for human traffic on it. Wolverines appear to be very sensitive to disturbance at natal den sites and will move newborn young if disturbed. Natal den sites have been located in secluded high-elevation cirque basins, and these areas may be frequented by snowmobilers and crosscountry skiers.

Wildlife will frequently *avoid habitats* in the vicinity of roads and similar transportation corridors because of repeated disturbances along the corridor or as a result of the death of less wary animals. Habitat avoidance may also occur in the vicinity of trails, cutlines, and seismic lines, although wildlife appears to avoid these smaller disturbance corridors less than roads. The degree of avoidance is again species-specific. Zones of influence used in cumulative effects models for grizzly bears range from 200 to 1,600 m for areas with hiding cover, and 800 to 3,200 m for open habitats. Black bear avoidance of open roads appears to be less than that of grizzlies. Habitat avoidance in the vicinity of linear developments has not been reported as frequently for wolves as for bears. However, the avoidance of open roads by wolves can be inferred from the absence of wolves in landscapes with road densities >0.6 km/km^2. Cougars may also avoid areas with higher road densities when establishing home ranges. Among the ungulates, elk are most likely to avoid habitat in the vicinity of disturbance corridors in areas that are hunted. Avoidance distances of 200 m to >1,600 m have been documented in the northwestern U.S.A. Habitat effectiveness may decline by at least 50% at road densities of 1.24 km/km^2. In unhunted areas, avoidance is either nonexistent or very temporal in nature. Deer may also avoid roads, but to lesser degree than elk. In northeastern Alberta, disturbance corridors including pipelines and seismic lines were avoided by woodland caribou in winter. Avoidance of habitats in the vicinity of corridors may vary seasonally.

Both grizzlies and black bears appeared to avoid roads less in the spring than in the fall. Similarly, elk avoided roads least in the spring and most in the fall. Habitat avoidance probably does not occur in the vicinity of railway rights-of-way.

Corridors may also act as *filters* or complete *barriers* for wildlife. The extent that a corridor is a filter depends upon the species of wildlife and attributes of the disturbance corridor. Species that are disturbed less by humans and that frequently do not avoid habitats in the vicinity of roads are probably not greatly impeded in their movements by roads (e.g., coyote, badgers). However, the movements of species which do avoid habitats in the vicinity of roads are likely affected. Wolverines and adult female grizzly bears have not been documented crossing the TransCanada Highway in the Bow River valley of Banff National Park (but they have crossed in 3 of 6 cases in Yoho), although other carnivores like cougars and wolves do cross. Width, curvilinearity, and traffic volumes probably affect wildlife crossing rates. Learning about roads and travel routes across them may play an important role in longer-lived species (e.g., cougars, wolves), provided that indirect mortality rates associated with the road are not too high. Pipelines under construction may be significant filters to ungulate movement. Elk, moose, and deer had difficulties crossing welded pipe strings when they were left above ground on blocks prior to burial. Visibility across the right-of-way and the number of pipes, berms, and ditches appeared to be the major factors affecting the willingness of all ungulates to cross these disturbances. Conversely, completed buried pipelines, seismic lines, and trails were not significant filters to wildlife movement. However, deep snow could reduce crossing success under elevated pipelines. Crossing success is related to the ground clearance of the pipeline and increased snow depths reduces ground clearances. Railways probably do not act as barriers to most large mammals, although small mammals (e.g., microtines) may be affected.

Habitat disruption for wildlife occurs when habitat is lost to disturbance corridors. Typically, habitat lost makes up a small fraction of the landscape. In addition, the disturbance effect is probably small when compared to the effects of habitat avoidance and mortality, direct and indirect.

Habitat enhancement may be associated with road corridors. Closed roads or roads with little traffic are frequently used as travel routes for wide-ranging ungulates and large carnivores, probably because such use is beneficial from an energetic standpoint (e.g., wolves, black bears, grizzly bears, elk, caribou, deer). Since pipelines and seismic lines typically have fewer people associated with them, they are probably more important as travel routes to wildlife than are roads. Roads may be used more frequently at night (e.g., grizzly bears). When corridors like roads and railways create openings in forested habitats, vegetation recolonizing the disturbed right-of-way and reseeded vegetation may provide food resources not available in the surrounding matrix. Ungulates and bears are attracted to these areas because of the high concentrations of food. Carnivores may in turn be attracted to these areas to prey on herbivores concentrated there. However, the advantages gained by using this habitat may not benefit wildlife in the long term since mortality risks, direct and indirect, are also greater along road rights-of-way.

Collisions with vehicles and trains are a *direct mortality* source for wildlife living in the vicinity of road and railway corridors, respectively. Virtually all species of wildlife including birds suffer from collisions. However, species and individuals that do not avoid corridors are more likely to be victims than those that are not frequently found in their vicinity. Elk, deer, bighorn sheep, and black bears attracted to early green-up of road rights-of-way are frequently hit. Moose are killed on roads and railways most often in winter when deep snow limits their movements outside of plowed rights-of-way and in spring when roadside ponds with high concentrations of salt from road runoff attract them. Significant numbers of caribou-vehicle collisions were also the result of the attraction to road salt. Grizzly bears habituated to traffic may also be victims although collisions do not appear to be a frequent occurrence for them. Many other factors associated with attributes of the road right-of-way and its location within the surrounding matrix may influence wildlife-vehicle collisions.

Most sources of *indirect mortality* along disturbance corridors are related to human access. Wildlife populations that are subjected to hunting and trapping sustain increased mortalities as a result of better access (e.g., grizzly bears, black bears, wolves, cougars, wolverines, elk, deer, caribou, mountain goats). Other sources of indirect mortality include poaching and management actions (elk, deer, grizzly bears, cougars, wolves). Increased predation arising from carnivore use of corridors is an indirect cause of mortality for many prey species (e.g., wolves and caribou in winter).

Population effects have been identified in wildlife populations that suffered losses directly attributable to development corridors. Historically, mountain goat and caribou population declines due to overhunting have been linked to access. In the Greater Yellowstone Ecosystem, grizzly bears probably suffered significant demographic consequences as a result of indirect mortality. In the Swan Mountains of Montana, grizzly bear mortality associated with road access and unnatural food sources, in conjunction with natural mortality, inhibited population growth. Population effects have been documented frequently among bird species in the vicinity of linear developments. Since demographic parameters of many wildlife populations are not known, whether mortalities related to roads are causing significant population effects are also not known. Similarly, since the extent of kill on railways has not been adequately documented, it follows that the importance of train-caused mortality for local wildlife populations is unknown. To establish the presence of a population effect, the demographics of the population must be studied.

Disturbance effects related to *powerlines* and their rights-of way have aspects that are similar to trails, seismic line, and pipeline corridors in that the rights-of-way allow access for humans. They also have unique disturbance effects because of the presence of the powerline. Raptors nesting on powerline support structures and birds using the powerline for resting, roosting, and hunting may be disturbed by humans. Responses to human disturbance are species-specific. Among raptors, certain species appear to have lower tolerances than others (e.g., ferruginous hawks vs. red-tailed hawks). Responses to human disturbance may also be influenced by hatching chronology. Incubating birds are more likely to abandon nests. Once eggs have hatched, the likelihood of nest abandonment declines. Electrocutions and collisions with transmission lines are 2 sources of direct mortality associated with powerline corridors.

A wide variety of techniques exists to mitigate the effects of linear developments on wildlife. Mitigation techniques vary in their usefulness depending on a wide variety of factors including the target wildlife species, geographic location, and disturbance corridor type. The most effective measures to mitigate the effects of these corridors occur at the landscape scale, since development and disturbance corridors have their greatest effects at that level. In addition, many species that are sensitive to disturbance have land requirements that must be viewed at the landscape scale (e.g., grizzly bears, wolverines). Planning development corridors at the regional or landscape scale provides the greatest opportunities for mitigating the effects of these disturbance corridors on these species.

Most regions are affected by development and development corridors to some degree and in many cases disturbance to wildlife occurs as a result of many different factors. The effects of human disturbance tend to accumulate within landscapes. Cumulative effects assessment (CEA) and geographic information systems (GIS) have been used as powerful tools in assessing the cumulative impacts of linear developments on wildlife. New CEA techniques and the use of GIS for analysis will provide better ways of assessing the effects of linear developments on wildlife.

Since the detrimental effects of disturbance may accrue in wildlife populations without generating obvious population responses (e.g., precipitous declines), regional planning in the future may require that different interests use regions or landscapes in a staggered fashion. By reducing the levels of human use in a landscape over a given period, the deleterious cumulative effects of several disturbance activities occurring at the same time can be avoided. This staggering of use should include public access. Public access for recreational purposes, particularly hunting, probably results in the most detrimental disturbance effects of development corridors.

Once planning at the regional or landscape scale has identified the kinds of disturbance effects that may occur as a result of linear development, then specific remedial actions can be planned. The first and foremost way to avoid the disturbance effects of development corridors is to minimize the number of corridors that are constructed. The necessity of each and every disturbance corridor in a planned development should be reviewed as to its purpose, necessity, and redundancy. There are many examples of ways that the number of disturbance corridors into an area can be reduced through thoughtful planning and cooperation within and between different resource sectors. Any reductions in the number of development corridors in an area will be beneficial to wildlife since additional disturbance effects are avoided.

Open road densities are a useful measure of the ecological effects of roads on a landscape. Road density thresholds -- the density of roads above which a species no longer occurs in an area -- have been determined for wolves in the northcentral U.S.; wolves rarely occupy areas with road densities greater than 0.6 km/km^2. Allowable road densities in grizzly bear recovery zones in the U.S. range from 0.47 km open $road/km^2$ to 0.62 km/km^2. In areas where the conservation of these species is an objective, open road densities should be maintained below these thresholds.

The most powerful tool available to reduce the effects of disturbance corridors on wildlife is access management, the control of human use of the development corridor. Access management should include the creation of low-quality access to discourage other human use, narrower seismic lines (4 m versus 8 m conventional lines), reclamation of old and temporary access roads including rolling slash back onto the roads and the removal of bridges and culverts, manned and unmanned gates at access points, and education both externally with the traveling public and internally with field staff. Community support is necessary. All resource users need to accept the basic tenet that disturbance corridors are detrimental to wildlife and increased human use of these corridors increases the number and severity of detrimental effects. This support is often difficult to obtain from recreational users who feel they have a right to use new access roads developed on public land.

External and internal attributes of disturbance corridors can be altered to reduce their filter or barrier effect. Whenever possible, corridor width should be minimized. Curvilinearity should be increased where possible (e.g., doglegs in pipeline rights-of-way). Roads should be developed and maintained to the minimum standard necessary for their stated purpose. Low road standards deter use, and promote lower vehicle speeds and reduce the likelihood of collisions. The effects of disturbance corridors can be substantially reduced by routing them to avoid areas where disturbance may be greater or unacceptable. Prior knowledge of wildlife use in a landscape is necessary to plan the alignment of a development corridor to minimize the effects of disturbance. When roads or other disturbance corridors open to public travel are routed around specific wildlife habitat to reduce the corridor's impact on a particular species, the chosen route should take into account the typical avoidance buffers documented for that species.

Other mitigation techniques include fencing, culverts, underpasses, overpasses, optical game warning devices, warning whistles, signs, modified speed limits, and education programs. The usefulness of some of these techniques have been questioned (e.g., optical game warning devices). Unfortunately, the efficacy of many of these techniques has not been rigorously examined even in areas where they have been in use for extended periods. There is an urgent need to conduct these kinds of assessments.

Most mitigation measures carry a price tag; in some cases the cost can be substantial. However, if one of a development project's objectives is the reduction of disturbance effects on wildlife, then these costs should be viewed as an integral part of disturbance corridor construction and maintenance. The economics of development should take in account the costs of maintaining functioning, intact ecosystems with self-sustaining wildlife populations.

This review should be considered a reference to be used when information is required regarding the effects of linear development on wildlife; it is not meant to be read from cover to cover. In addition, the review should be a starting point for those interested in understanding the effects of linear developments on wildlife. Although we tried to be comprehensive, the resulting bibliography must still be considered a selection of the literature available on the subject. This is a very dynamic field with new findings published every month in major scientific journals. Even as this report was prepared, new information was appearing that could not be included in the bibliography. We encourage readers to go beyond this bibliography and conduct their own searches of the current literature in their specific areas of interest to ensure that the best scientific information is used in assessing the effects of linear developments on wildlife.

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1.0 Introduction

Do roads and other linear developments have significant effects on wildlife? When a linear development is constructed in a previously-undisturbed landscape, are wildlife populations affected, and if so, how? When behavioural effects of disturbance (e.g., habitat avoidance) are identified, are population effects (e.g., population declines) also occurring? Are effects different for different species of wildlife and in different habitats? Research into the effects of linear developments on wildlife has been on-going for decades to try to find answers to these and other related questions. Data regarding the effects of linear developments on wildlife have been reported in the scientific literature but, in many cases, the results have not reached the general public or the resource business sector.

Arc Wildlife Services Ltd. was contracted by the Canadian Association of Petroleum Producers, the Alberta Energy and Utilities Board, and Nova Gas Transmission Ltd. to conduct a review of the scientific literature describing the effects of linear developments on wildlife, especially large mammals. Of particular interest were the types of roads and linear developments created by the oil and pipeline industries in western Canada. This report and the accompanying electronic bibliography are the final product of the contract.

This report was not written to be read from cover to cover. It should be considered more as a reference to be used when information is required regarding the effects of linear development on wildlife. The report is divided into a number of sections. The basis of the literature review was an electronic search of biological and related electronic databases. The scope of this research is detailed in Section 2. Since the basis for understanding the effects of linear developments on wildlife is the ecology of landscapes, Sections 3 provides an introduction to the basic concepts of landscape ecology and Section 4 outlines the major functions of disturbance corridors. The effects of linear developments on wildlife can be divided into 6 major groupings, and these are outlined in Section 5. Section 6 examines the effects of linear corridors from the perspective of corridor type. Sections 5 and 6 are meant to be brief overviews of their respective topics. Section 7 forms the bulk of the report and examines, in detail, the effects of linear developments on different wildlife species and species groups. Large mammals are dealt with at the species level, whereas medium-sized carnivores are dealt with as a group, as are birds. Although small mammals, lizards, and amphibians were included in the electronic search, results of those searches were not summarized in this report. The final section, Section 8, briefly reviews mitigative measures currently in use. The written report does not have a literature cited since this was deemed redundant. All references to the literature in the report are listed as record numbers from their respective locations in the accompanying electronic database.

This review should be considered a starting point for those interested in understanding the effects of linear developments on wildlife. Although we tried to be comprehensive, the resulting bibliography must still be considered a selection of the literature available on the subject. Literature not indexed in electronic form -- generally material published prior to 1990 -- was not searched because of the time constraints necessarily built into a project with such a broad mandate. In addition, this is a very dynamic field with new findings published every month in major scientific journals. Even as this report was prepared, new information was appearing that could not be included in the bibliography. For these reasons, we encourage readers to go beyond this bibliography and conduct their own searches of the current literature in their specific areas of interest to ensure that the best scientific information is used in assessing the effects of linear developments on wildlife.

2.0 Methods

The basis for this review of the impacts of linear developments on wildlife was searches of electronic databases at the University of Calgary, the University of Alberta, and the Alberta Environment library. Databases that were searched are listed in Table 1. Each database was searched for literature related to the topic using keywords (Table 2). Keywords were searched in all their forms, that is, singular, plural, or by the root (truncation). For example, searches for the word "wolf" would include a separate search for "wolves". Keywords and keyword searches were developed for each database and varied depending on the search capabilities and subject orientation of each database. Typical searches were conducted in a step-wise fashion. Words from group #1 (Table 2) were used first to create a list of wildlife-related records. In some databases, common words like "nonhuman" and "mammal" could be used instead of searching for individual species because of the use of orders and families as key words in those databases. The wildlife record list was then used as the basis for searches using words from groups 2-5 in various combinations.

Table 1. Databases searched at the University of Calgary, University of Alberta, and Alberta Environment library.

Biological Abstracts on CD	1990 - 1996 (March)
Wildlife Review	1971-1996 (May)
Environmental Abstracts	1975-1995 (June)
Dissertation Abstracts Ondisc	1981-1996
Agricola	1984-1996 (June)
Microlog	
UN Index	
University of Calgary Online catalogue/Clavis	

Records were downloaded onto floppy disks and, using BiblioLink II, were loaded directly into the ProCite 3.1 database. The linear corridor concept required keywords that were not distinctive and this resulted in a very large number of records to review since many records with the chosen keywords were not pertinent to this bibliography. The electronic database currently contains approximately 2,200 references.

Once the electronic search was completed, subsets of the database were created for each species or species group. Abstracts from all papers were reviewed and most original papers were read. Notes regarding the impacts of linear developments were often added to a record in the database after the paper was reviewed. When papers were reviewed, the literature cited sections were also perused for additional pertinent references. These references were collected, reviewed and added to the database. In this fashion, older literature on the topic has been included in the database even though most of the electronic searches were from more recent literature. Since this type of searching was not comprehensive, older literature is probably under-represented in the database.

Table 2. Keyword groupings used for electronic searching of databases.

Group 1.	wildlife, ungulate, cervid, mule deer, white-tailed deer, elk, moose, caribou, mountain goat, mountain sheep, bighorn sheep, thinhorn sheep, Dall's sheep, Stone's sheep, cougar, mountain lion, puma, panther, bear, grizzly bear, black bear, wolf, wolverine, fisher, marten, lynx, bobcat, river otter, birds, raptors, reptiles, amphibians
Group 2.	street, road, trail, highway, freeway, motorway, expressway, overpass, underpass, culvert, right-of-way, OHV, ATV, off-highway, all-terrain, off-road
Group 3.	pipeline, transmission line, powerline, seismic line
Group 4.	fragmentation, disturbance, mortality, corridor, access, barrier
Group 5.	logging, timber, forest, lumber, clearcut
Group 6.	mining, siltation, sediment, erosion

3.0 Definitions: Landscapes, Mosaics, Patches, Corridors, and Matrices

The effects of linear developments on wildlife are best understood in the context of regional and landscape ecology: the spatial arrangement of ecological processes on the land. Forman (951604) presents an excellent discussion of the concepts of landscape and regional ecology and the following text draws from that work unless otherwise noted. The concepts and terms used in this overview need to be understood since they are central to the detailed discussion of disturbance effects in the species and species groups summaries later in the report. We encourage readers to consult Forman (951604) and other texts on landscape ecology for a more in-depth discussion of these and related topics.

The land we live on can be considered a **mosaic**, a pattern of objects on the land that can be divided into three basic units: patches, corridors, and matrices. A **patch** is a reasonably homogenous non-linear area that differs from its surroundings. Similarly, **corridors** may be defined in general as reasonably similar linear areas that differ from their surroundings. Finally, a **matrix** is the background ecosystem, or land-use type in the mosaic. These 3 landscape elements may be of either natural or human origin. Using these broad definitions, a patch could be anything from a well site to a marsh. Roads, seismic lines, and hedgerows are examples of corridors, and a matrix could be a forest, a prairie, a rural subdivision, or a farming area. This examination of the effects of linear developments on wildlife will focus on the effects of **disturbance corridors** like roads and powerline rights-of-way since they are more commonly encountered in oil and gas activities. However, **remnant corridors**, long, narrow strips of original habitat in an otherwise disturbance-dominated landscape (e.g., roadside verges in an agricultural landscape or forest strips in a logged forest environment), are also important to wildlife and are discussed where appropriate.

Scale is an important concept within the study of landscapes and regions. A **landscape** is a kilometres-wide mosaic of ecosystems. Within a landscape, there is a recurring pattern of patches, corridors and matrices. The matrix and the type and configuration of patches and corridors on that matrix determine the viability of the landscape for different species of wildlife. **Regions** may contain many landscapes, but there is not necessarily a repeating pattern of landscapes or landscape elements. At this larger scale, the type and spatial arrangement of landscapes determine an area's suitability for different wildlife species. When considering the effects of development corridors like roads on wildlife, scale is of utmost importance. Wildlife species that are sensitive to human disturbance and that have large area requirements (e.g., grizzly bear) are more likely to be affected by linear developments than widespread species that require less space (e.g., snowshoe hare), since the former are more likely to encounter a development within their home areas . However, species which are not widespread within a landscape and are dependent on particular landscape elements for their survival (e.g., long-toed salamander and ponds) may also be significantly affected by a linear development if the development removes or affects a critical landscape element.

4.0 Corridors

Development corridors may affect wildlife in a wide variety of ways. The range of effects of any particular corridor has is in part a function of the corridor itself. Corridors have both internal and external structure. Forman (951604) grouped **internal structure** characteristics into 3 categories: width characteristics, internal entities, and plant and animal community structure (Fig. 1). **Width** characteristics include the environmental gradient across a corridor (i.e., moving from adjacent habitat across the edge to the interior of the corridor and back across to the edge to the opposite bordering habitat) and edge characteristics (e.g., abrupt vs. uneven), and the effects of different habitats on either side of the corridor. The portion of a corridor, patch, or matrix near its perimeter is referred to as an **edge**. Corridors have a high edge-to-area ratio because they are, by definition, long and thin. The **edge effect** refers to the high population density and diversity of wildlife that typically occurs along edges. **Internal entities** refer to structures like roads or ditches within a right-of-way clearing.

A powerline right-of-way through a forested ecosystem can be used to illustrate the different internal characteristics of a disturbance corridor. The powerline right-of-way will have a cleared area of a particular width depending on the size of the powerline. The width of the cleared area will have a direct effect on which plant and animal communities are present. Narrow rights-of-way are dominated by edge species while wider disturbance corridors are more likely to support a more diverse assemblage of species including species that are dependent on habitat within the corridor. In addition, there often are different habitats longitudinally along the corridor depending on its slope, aspect, and moisture regime at any given point (e.g., wetter north and east-facing slopes may have shrub communities while drier south and west-facing slopes may have grassland habitats). These different vegetation communities will also support different wildlife communities. Between the edges of the clearing, there generally is a vehicle track (an internal entity) used by maintenance trucks traveling along the corridor.

External structure refers to the corridor's structure in the surrounding matrix (Fig. 2). External structure includes a wide variety of factors such as a corridor's relationship to its surroundings (e.g., corridor length, patchiness, distribution of attached nodes, adjoining patches or matrix), curvilinearity and width (variability in width, distribution of narrows) and connectivity and gaps (gap sizes, gap frequency, habitat suitability in and around gaps). **Connectivity** refers to the degree to which an ecosystem is connected or joined together. For forest-dwelling wildlife living in landscapes divided by disturbance corridors, the degree of connectivity is inversely related to the number of disturbance corridors that divide the landscape into disjointed pieces. Landscapes with high connectivity typically have few disturbance corridors. Once again corridor structure is important. In Fig. 2, connectivity decreases with increased width of the right-of-way. Connectivity will be best across forest trails and will be progressively worse as right-of-way width increases. Divided highways may be complete barriers to movement for some species. Increased curvilinearity in a disturbance corridor probably increases connectivity between bordering habitats since sight lines are shorter; winding roads through forested habitat affect connectivity less than long, straight seismic lines.

Corridors affect wildlife in many different ways. However, these can be grouped into 5 functions (951604): corridors act as habitat, conduits, filters or barriers, sources, and sinks. Corridor structure discussed above plays a major role in determining the extent to which a corridor fulfills each of the 5 functions.

4.1 Habitat

Disturbance and remnant corridors may act as habitat for wildlife. Food resources are often concentrated along these corridors. The removal of a closed-canopy forest when a seismic line is cut allows sunlight to penetrate to the ground, promoting a more diverse plant community than may occur in habitats on either side. These plant communities are often rich in species that are important food resources for herbivores. Wildlife species from small mammals and birds to ungulates take advantage of the habitat created by disturbance corridors. Typically edge and habitat generalists predominate in corridors, while interior species (species that require intact, undisturbed patches of habitat) with more specific habitat requirements are absent. Corridor width typically limits the presence of species with wide home ranges. Generalist microtines (e.g., deer mouse*)* and birds (e.g. pine siskins) as well as grazing ungulates like elk use disturbance corridors for feeding. Browsing ungulates like moose frequently take advantage of shrub species that proliferate along the edges of both remnant and disturbance corridors. Birds, including ducks, will use remnant corridors, like roadside verges, for nesting habitat. The abundance of small mammals and birds along these corridors may attract small and medium-sized carnivores that are less affected by human disturbance. Coyotes that are attracted to the small mammal communities living in the TransCanada Highway corridor through Banff National Park are a good example. Ravens are more common along roads than elsewhere because carrion is available more frequently along these disturbance corridors.

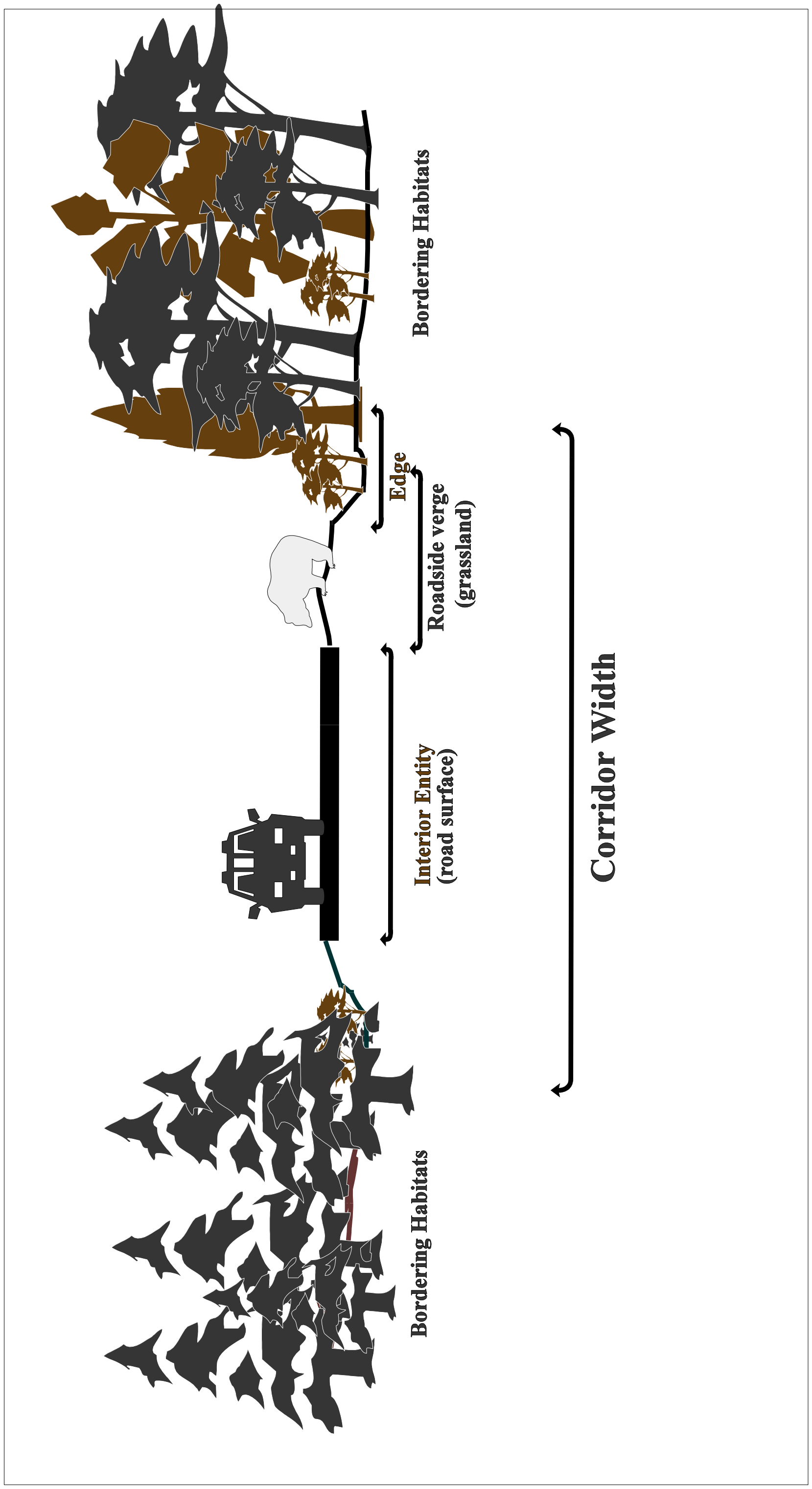

Figure 1. Internal structure of a road corridor.

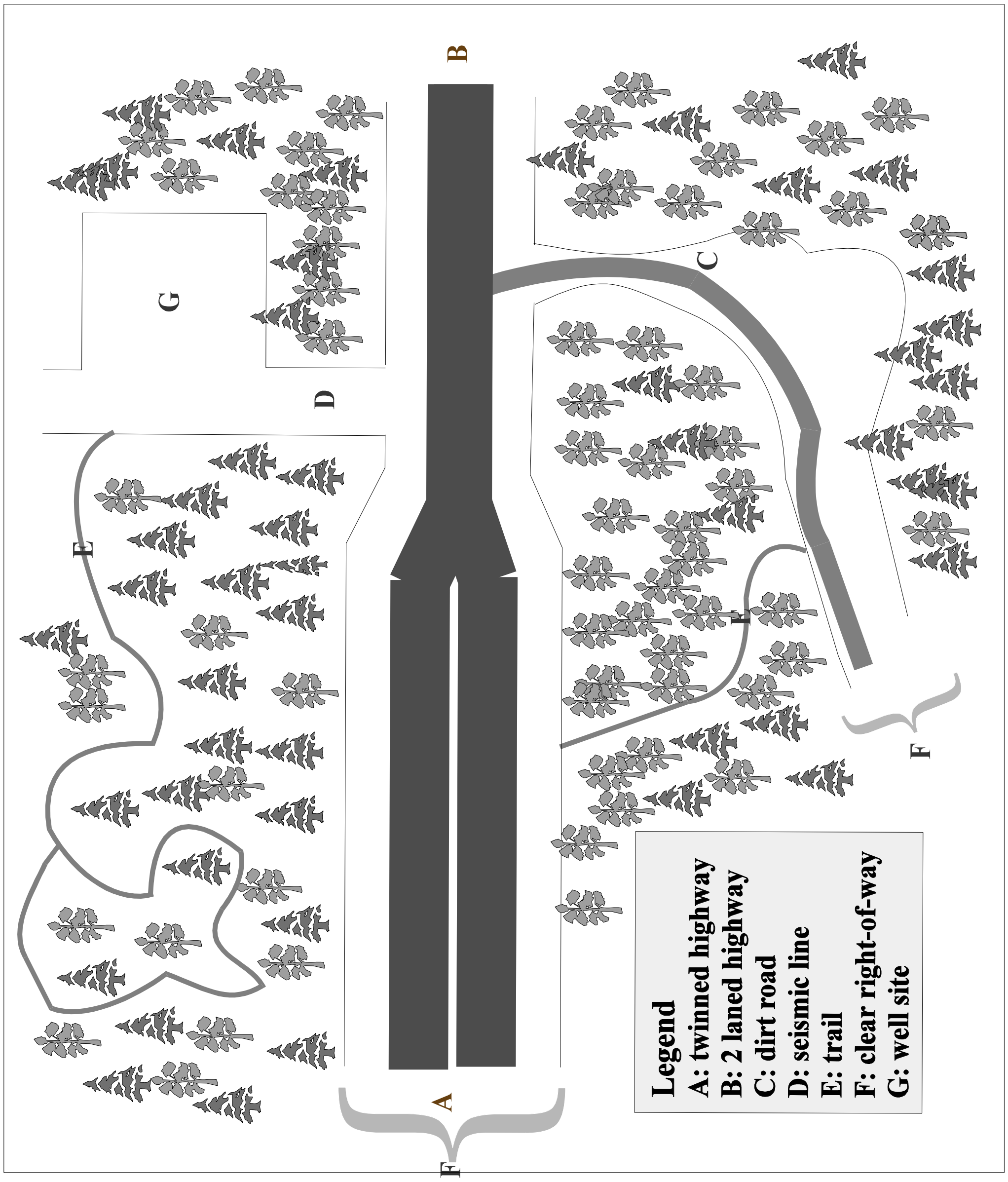

Figure 2. External structure of a corridor.

4.2 Conduits

Disturbance and remnant corridors may act as routes for wildlife movement. These movements may be activities within home ranges, dispersals, or movements associated with mating or migration. External and internal structure of the corridor, as well as the specific requirements of different wildlife species, will determine the extent to which a corridor is used for movement. Bears will make use of seismic lines and trails to travel within their home ranges provided that human disturbance along the corridors is not excessive. Elk and caribou use backcountry roads and seismic lines when migrating between seasonal ranges. Wolves and coyotes use packed snowmobile trails to reduce energy expenditures while traveling during winter. Dispersing microtines will use roadside verges as travel corridors.

4.3 Filters, Barriers and Fragmentation

Wildlife may be inhibited from crossing disturbance corridors from intact habitat on one side to habitat on the other side. If a disturbance corridor is a **barrier**, then no movement occurs across it. If some movement occurs but the rate of movement is less than through intact habitat, then the corridor is considered a **filter** to animal movements. A remnant corridor may also act as a filter. Certain species of wildlife, or perhaps even certain individuals in a local population will use a remnant corridor but others may not. The degree of connectivity of a remnant corridor, that is, its width and number of gaps along its length, will often dictate which species and individuals will use it.

The degree of movement that a corridor allows is referred to as the corridor's **permeability**. If a disturbance corridor has low permeability, then habitats and wildlife populations on either side of the corridor may become functionally separated. Habitats and wildlife which are functionally separated are fragmented and the process is referred to as **fragmentation**. Fragmented landscapes have poor connectivity.

4.4 Sources

A disturbance corridor may act as a source of wildlife in that it may contribute wildlife to the surrounding habitat it passes through, the matrix. Wildlife passing along a corridor -- that is, using the corridor as a conduit -- may spread out into the matrix affecting wildlife populations there. Since edge species and habitat generalists are typically more abundant in corridors, they are the species most often using the corridor in this manner.

4.5 Sinks

Corridors may also attract wildlife from surrounding habitats (the matrix) leading to their deaths. Disturbance and remnant corridors may act as sinks in both direct and indirect ways. Direct mortality may result, for example, from bird strikes and electrocutions on power lines or from collisions with vehicles on roads. Indirect mortality often occurs because humans or predators are using the corridor as a conduit. Humans are, in almost all cases, the most important source of mortality for wildlife, whether it's through legal hunting and trapping, poaching, or management actions associated with our inability to coexist with certain species of wildlife. Since disturbance and remnant corridors often are preferred habitat for many prey species, prey may be particularly abundant and this in turn attracts predators. A corridor, essentially a long, narrow patch, can be hunted more efficiently than patches with higher area-to-edge ratio (e.g., circular patches), often resulting in high mortality rates for prey species in corridors. However, the corridor may also act as a sink for the predator. Predators themselves are exposed to higher mortality as a result of humans in the corridors.

5.0 Disturbance Effects

The effects of development corridors on wildlife can be subdivided into 6 major categories. The first 5 result directly from the 5 corridor functions described in the previous section and the sixth effect takes into account the numerical consequence of a disturbance on a wildlife population as a whole (i.e., demographic parameters). The presence or absence of any particular effect is dependent on the species of wildlife and the structure of the corridor. One species of wildlife, elk, and 1 disturbance corridor, a pipeline right-of-way in the foothills of the Rocky Mountains, will be used throughout this section to illustrate each disturbance effect.

5.1 Individual Disruption

The disturbance corridor itself or activities associated with the corridor often disturb wildlife resulting in wildlife leaving the corridor area or altering patterns of use, responses that carry with them costs in terms of energy expenditure and possibly lost opportunities. In the case of elk on a pipeline right-of-way, the mere presence of the right-of-way would not disrupt elk. However, the right-of-way may provide access to humans. If elk were in the vicinity of the corridor when humans came along it, whether the people were on all-terrain vehicles, horses, or on foot, the elk would leave the area. For elk, leaving the area usually involves getting out of view of the disturbance. In open habitats, this may mean traveling over the closest ridge, while in closed coniferous habitats traveling into heavy cover may be sufficient. Typically, this effect is short term. When the people pass, the elk may choose to return and resume their activities. Individual disruption of elk causes them to expend energy to leave, and in the winter months this expenditure of energy may be considerable if the snow is deep and the topography is open and rugged. Presumably, elk choose to be where they are based on their needs at the time. By pushing them into other areas, there may be additional energy costs associated with the loss of security or foraging opportunities.

5.2 Habitat Avoidance

Disturbance corridors and activities associated with them or the death of less wary animals as a result of the disturbance corridor may lead to wildlife avoiding habitats close to the corridors. Habitat in the vicinity of the corridor is effectively lost. Fragmentation of the landscape may occur if avoidance of disturbance corridors prevents wildlife from fully using land on either side of a corridor. If elk are continually disturbed in a particular area along a pipeline right-of-way, they will avoid the area altogether, irrespective of whether there are humans in the vicinity at any given time. This avoidance of habitat may be temporal both on a daily basis and seasonally. Elk use land within several hundred metres of disturbance corridors like pipelines significantly less than expected during daylight hours if humans are present, and their avoidance of the area may be greater in summer, fall, and winter than in spring.

5.3 Social Disruption

Social disruption refers to any changes to the social structure of population as a result of the disturbance corridor. This disturbance may take several forms such as the displacement of wildlife from the corridor into adjacent habitats that are already occupied by other individuals of the same species, changes in group structure for gregarious species, or differential mortality of classes as a result of the disturbance corridor. For elk along the pipeline right-of-way, frequent disturbance by humans could result in smaller group sizes and attendant increases in predation risk. Finally, if bull elk are hunted, mature bulls in an elk population living in the vicinity of a pipeline may have higher annual mortality rates because of increased human access. The bull age structure may change, changing the dynamics of the fall rut.

5.4 Habitat Disruption or Enhancement

Disturbance corridors may remove or provide additional habitat for wildlife. Examples of habitat disruption include the construction of all types of road or entire road rights-of-way if they are fenced. Habitats may be enhanced for wildlife if new habitat features are created along corridors that were not present prior to the construction of the corridor. New habitat may be beneficial to wildlife residing in the surrounding habitat or it may provide opportunities for new wildlife species to colonize an area.

The pipeline right-of-way could disrupt habitat or enhance it. Pipeline rights-of-way may provide additional grazing for elk. These rights-of-way are often the first areas to green-up, so they fulfill an important nutritional role for elk during a time when new growth is not yet available elsewhere. In addition, shrubs generally proliferate along the corridor edge proving winter browse. Alternatively, habitat may also be removed if a road is constructed along the pipeline right-of-way for maintenance and the amount of vegetation available for consumption by elk declines.

5.5 Direct and Indirect Mortality

Activities associated with disturbance corridors may result in mortalities. Examples of direct sources of mortality are wildlife-vehicle collisions or powerline strikes and electrocutions. Disturbance corridors may also be important contributors to indirect mortality. Indirect mortality is typically associated with human access. Prior to the existence of a development corridor, humans are often absent from the landscape. However, once a disturbance corridor is present, human access generally leads to additional mortality due to hunting, trapping, poaching, and management actions.

Predators such as wolves may benefit from the presence of the disturbance corridor in a similar way.

Direct mortality as a result of the pipeline corridor would probably not occur. However, the disturbance corridor would allow access to hunters whether motorized or not, increasing the likelihood that elk in the population were killed. In addition, if a trapper or cross-country skiers created a packed trail along the corridor, predators like wolves could use this route to travel through elk habitat, possibly increasing their access to the elk population. Indirectly then, the presence of the disturbance corridor could increase elk vulnerability to wolf predation.

5.6 Population Effects

Shank (9230) pointed out that behavioural responses to disturbance may have demographic consequences (i.e., population effects). However, population effects don't necessarily follow even from behavioural responses. It is also possible that population effects may occur even though no behavioural response to a disturbance was detected. For example, we know that overt behaviour is a poor indicator of general arousal based on heart rate telemetry work conducted on bighorn sheep (810). Direct mortalities, whether related to linear developments or not, obviously have population effects on wildlife. However, aside from direct mortality, the indirect effects if disturbance on wildlife *populations* are difficult to confirm and quantify. To confirm the presence of a population effect, the demographics of the population must be studied.

Any population effects of disturbances associated with the pipeline right-of-way would require that the demographic parameters of the elk population be determined over an extended period of time. If the herd was declining, then the causes of the decline would also have to be examined. Typically, there are many possibly synergistic factors that may cause a decline (e.g., habitat changes, predator-prey dynamics, weather variables) and showing a cause and effect relationship between the disturbance corridor and a population decline in the elk herd would be very difficult.

6.0 Linear Development Types

Different types of disturbance corridors have different effects on wildlife, both in the type and the magnitude of effect. The following discussion summarizes the effects roads, railways, trails, pipelines, seismic lines, and powerlines have on wildlife. For each disturbance corridor type, effects on wildlife are grouped according to the 6 categories discussed in the previous section: individual disruption, habitat avoidance, social disruption, habitat disruption or enhancement, direct and indirect mortality, and population effects. Additional detail regarding effects on individual species can be found in the species and species group summaries.

6.1 Roads

Of all disturbance corridors humans create, roads probably have the greatest impact on wildlife populations. The following discussion includes roads of all sizes from interstate highways to small forest roads.

Individual disruption occurs in the vicinity of roads for all wildlife species. The degree of disturbance exhibited by different wildlife species in the vicinity of roads varies. Certain species of large mammals like grizzly bears, wolverines, and elk tend to be more sensitive to disturbance than others like bighorn sheep, mountain goats, or marten. Efficient foraging strategies of grizzly bears may be disrupted by roads (960). Cougars may shift their activity patterns in the vicinity of human disturbances like roads from crepuscular to nocturnal (1990, 9840). Wolves are sensitive to disturbance near their natal dens and road traffic may cause wolves to move pups to less-disturbed areas (850). Large birds tend to be more sensitive to disturbance than smaller birds (e.g., 15370).

The road itself typically does not cause a disturbance response; it's the human presence on the road that causes disturbance (7570, 2610, 6600, 9600). Closed roads are generally not avoided by wildlife. On roads open to traffic, vehicles that never stop may be ignored in some cases, even among more sensitive species like elk (12310). However, stopped vehicles and people leaving their vehicles cause increased levels of disruption. In Denali National Park, increased disturbance to Dall's sheep and caribou was directly related to people getting out of stopped vehicles (9320). Birds react in a similar fashion. Incubating trumpeter swans do not react to passing road traffic but stopped vehicles and pedestrians caused birds to leave their nests more often (6230).

Typically, hunted wildlife populations exhibit stronger disturbance reactions to people along roads than does wildlife in protected areas. In this manner, elk in national parks may be seen along roadside verges (12310), when the same species is very rarely seen close to a road elsewhere (860). Similarly, flight distances from vehicles for antlered white-tailed deer in hunted populations were significantly longer than in unhunted populations in the Adirondack Mountains of northern New York (9600).

The experience of individuals appears to have a great effect on the degree of disturbance. Within a national park, elk in the backcountry that are not frequently exposed to humans exhibited greater levels of disruption when confronted by humans than elk residing in the immediate presence of people in the same national park (15360). Dall's sheep in Denali National Park exhibited disturbance responses while crossing a highway during migration even though the highway had been there for more than 50 years (4680). In this case, the sheep were not exposed to roads and traffic most of every year and had not habituated to it. Grizzly bears are known to avoid open roads in general, yet in protected populations, some bears become habituated to the point that they will use roadside verges with apparent disregard for human traffic on it (950098, 30, 950094).

Wildlife will frequently **avoid habitats** in the vicinity of roads and similar transportation corridors because of repeated disturbances along the corridor. The degree of avoidance is again species-specific. Grizzly bears typically used habitat within about 500 m of roads less than expected (e.g., 247). Zones of influence used in cumulative effects models for grizzly bears range from 200 to 1,600 m for areas with hiding cover, and 800 to 3,200 m for open habitats (950101). Black bear avoidance of open roads appears to be less than that of grizzlies (e.g., 455). Habitat avoidance in the vicinity of linear developments has not been reported as frequently for wolves as for bears. However, in the Bow Valley in Banff National Park, human developments including the TransCanada Highway appeared to have alienated wolves from over 62% of the best wolf habitat in the valley (280). The avoidance of open roads by wolves can be inferred from the absence of wolves in landscapes with road densities >0.6 km/km². Cougars may also avoid areas with higher road densities when establishing home ranges (951104, 1990)

Among the ungulates, elk are most likely to avoid habitat in the vicinity of disturbance corridors in areas that are hunted. Avoidance distances of 200 m to >1,600 m have been documented in the northwestern U.S.A. (e.g., 11870, 4620). By modeling the effects of road density on elk habitat effectiveness, Lyon (7580) calculated that habitat effectiveness may decline by at least 50% at road densities of 1.24 km/km². In unhunted areas, avoidance is either nonexistent or very temporal in nature. Deer may also avoid roads, but to lesser degree than elk (e.g., 13630). The degree of avoidance may be affected by the availability of preferred habitat away from roads. If less habitat is available away from the roads than near them, then deer and elk will be found closer to roads (11010).

Avoidance of habitats in the vicinity of roads may also vary seasonally. Both grizzlies and black bears appeared to avoid roads less in the spring than in the fall (e.g., 950097, 20, 247). Similarly, elk avoided roads least in the spring and most in the fall (e.g., 860). In the case of bears, this avoidance may be associated with either seasonal increases in traffic volume related to hunting or it may result from the distribution of seasonal foods if other variables like traffic volume are constant. Elk are likely avoiding hunters in the fall.

Roads may also act as filters or complete barriers for wildlife. The extent that a road is a filter depends upon the species of wildlife and attributes of the disturbance corridor. Species that are disturbed less by humans and that frequently do not avoid habitats in the vicinity of roads are probably not greatly impeded in their movements by roads (e.g., coyotes [951514], badgers [3850]). However, the movements of species which do avoid habitats in the vicinity of roads are likely affected. For example, wolverines and adult female grizzly bears have not been documented crossing the TransCanada Highway in the Bow Valley of Banff National Park (300, 18890, 230, 60), although other carnivores like cougars and wolves may cross (951044, 280). Width, curvilinearity, and traffic volumes probably affect wildlife crossing rates. Radiocollared lynx crossed Highway 93, a 2-lane paved highway, more frequently than the TransCanada Highway, a 4-lane highway with higher traffic volumes (C. Apps, pers. commun.). Learning about roads and travel corridors across them may play an important role in longer-lived species (e.g., cougars [950261, 300], wolves [280]), provided that indirect mortality rates associated with the road are not too high (see below, Indirect Mortality).

Habitat disruption for wildlife occurs when habitat is lost to roads. A single-lane road 6.7 m wide through elk habitat removes 0.68 ha per km from elk use (10570). An access road and 2 well sites removed 11.8 ha of sheep habitat in southwestern Alberta (5040). Typically, habitat lost to roads is a small fraction of a landscape. For example, in the sheep study area just mentioned, the habitat lost represented 2.7% of the bighorn sheep range (5040). To quantify the importance of habitat loss, the amounts of each habitat type should be determined. Loss of habitats that are both rare and important to wildlife are more important than habitats with extensive distribution. Again using the above-mentioned sheep project (5040), 5.7 ha of alpine habitat (19% of alpine tundra available) and 2.8 ha of fescue communities (2.1% of available fescue communities) were lost. These losses were considered minor for the bighorn sheep herd (5040).

When the proliferation of roads across North America is considered, the actual amount of land that has been paved or graveled is staggering. By the end of 1981, there were 6.2 million kilometres of improved public roads and another 161,000 km of primitive or unimproved roads in the U.S.A. (510). In surface area, improved roads accounted for the equivalent of the states of Rhode Island, New Hampshire, Vermont, Massachusetts, and Connecticut combined (510). What this represents in wildlife numbers cannot be estimated. However, even though the amount of land is considerable, the effect of habitat disruption on wildlife is probably small when compared to the effects of habitat avoidance and mortality, direct and indirect.

In addition, roads can disrupt habitat indirectly through the introduction of exotic plants, and pollutants like dust (e.g., 3860), salt (e.g., 5760), and vehicle emissions (e.g., 12940). For example, mule deer forage collected from roadsides in Rocky Mountain National Park, Colorado, contained lead (Pb) concentrations ranging from 0.8 to 50 µg/g.

Concentrations were inversely correlated with distance from the roadway. Equations developed to estimate deer absorption of Pb from contaminated roadside vegetation indicated that deer in some age classes needed only to consume 1.4% of their daily intake of forage from roadsides before consuming excessive amounts of Pb (12940).

Habitat enhancement may be associated with road corridors. Closed roads or roads with little traffic are frequently used as travel routes for wide-ranging ungulates and large carnivores, probably because such use is beneficial from an energetic standpoint (e.g., wolves [18370, 280, 950587], black bears [7640, 6023], grizzly bears [950265, 12210], elk [7010, 860], caribou [3860], deer [9100, 10160, 13550]). Roads may be used more frequently at night (e.g., grizzly bears [29]). When roads create openings in forested habitats, vegetation recolonizing the disturbed right-of-way and reseeded vegetation may provide food resources not available in the surrounding matrix. Ungulates (e.g., 12920, 7010, 860, 4180, 2600, 14000, 13550) and bears (526, 7690) are attracted to these areas because of the high concentrations of food. Carnivores may in turn be attracted to these areas to prey on herbivores concentrated there. Lynx (412) and fisher (951534) have been documented preying on snowshoe hares along road corridors. Similarly, coyotes are attracted to the fenced TransCanada Highway right-of-way to feed on microtines (951514). However, the advantages gained by using this habitat may not benefit wildlife in the long term since mortality risks, direct and indirect, are also greater along road rights-of-way.

Collisions with vehicles are a **direct mortality** source for wildlife living in the vicinity of a road corridor. Virtually all species of wildlife including birds suffer from vehicle collisions. However, species and individuals that do not avoid road corridors are more likely to be victims than those that are not frequently found in the vicinity of roads. Black bears and grizzly bears habituated to traffic may be victims of collisions (2770, 419, 840, 300). Collisions do not appear to be a frequent occurrence for grizzly bears (950102), but black bears in Canada's mountain parks are frequently hit (951634). Coyotes attracted to high microtine populations in the TransCanada Highway right-of-way suffer high mortality rates (951514). Similarly, elk, deer, and bighorn sheep attracted to early green-up along rights-of-way are also frequently hit (e.g., 7240, 590, 9960, 3880). Mountain goats do not appear to be susceptible to vehicle collisions even though they do cross roads seasonally to visit mineral licks (12690). Moose are killed on roads most frequently in winter when deep snow limits their movements outside of plowed rights-of-way (4800), and in spring when roadside ponds with high concentrations of salt from road runoff attract moose (5760). Caribou were frequently killed in westcentral Alberta when they were attracted to the right-of-way by road salt (260). Many other factors associated with attributes of the road right-of-way and its location within the surrounding matrix may influence wildlife-vehicle collisions (e.g., elk [1206], deer [4920, 8920, 15480, 12710]).

Most sources of **indirect mortality** are related to access. Wildlife populations that are subjected to hunting and trapping sustain mortalities as a result of better access (e.g., grizzly bears [951004], black bears [419, 32, 7690], wolves [905], cougars [951134, 951654], wolverines [18790], elk [2070, 2340], deer [5890, 10470], caribou [950587], mountain goats [1488, 950835]). Other sources of indirect mortality include poaching and management actions (elk [15630], deer [9090], grizzly bears [18801, 960, 898], cougars [951064], wolves [7820]). Increased predation arising from wolf use of packed trails or plowed roads is an indirect cause of caribou mortality (950242, 950587). Roads may also be a source of indirect mortality for birds. Interior-forest birds breeding along the right-of-way may incur increased nest predation by a variety of avian and mammalian predators (e.g., 18270, 16910, 13900), and parasitism by brown-headed cowbirds also increases (e.g., 13900).

Population effects are difficult to document unless population dynamics are studied directly (9230). However, population effects have been identified in wildlife populations that are suffering losses directly attributable to roads. Historically, mountain goat and caribou population declines due to overhunting have been linked to access (1488, 950944, 950835, 950639). In the Greater Yellowstone Ecosystem, grizzly bears probably suffered significant demographic consequences as a result of indirect mortality (951624). In the Swan Mountains of Montana, grizzly bear mortality associated with road access and unnatural food sources, in conjunction with natural mortality, inhibited population growth (882). In North Carolina, road kills threatened to extirpate a small isolated black bear population (840). Current levels of elk-vehicle collisions along Highway 93 in Kootenay National Park were considered contributory, along with habitat loss and natural mortality, to the observed decline in the park elk population (580). Since demographic parameters of many wildlife populations are not known, whether mortalities related to roads are causing significant population effects are also not known.

6.2 Trails, Pipelines, and Seismic Lines

The effects of trails, pipelines, and seismic lines on wildlife are similar in nature to the effects of roads discussed in the previous section. However, impacts tend to be less significant for these smaller corridors since their physical attributes are less disruptive (e.g., narrower rights-of-way, increased curvilinearity of trails) and fewer people are associated them.

Individual disruption may occur along trails, seismic lines and pipelines for many wildlife species. Deer were disrupted by humans along trails (12860, 9600, 10180), and disruptions tended to be greater for hunted deer populations (9600, 2890). Similarly, desert bighorn sheep that had been exposed to greater levels of hunting pressure in the past were disturbed more by hikers than an adjacent herd that had not been subjected to the same hunting pressures (4360, 950954). Humans on foot caused greater disturbances for deer than did humans traveling on snowmobiles (12860). However, snowmobiles may disrupt caribou on high-elevation winter range (11340). Elk may be disturbed by recreational users, particularly cross-country skiers (950717). In Yellowstone National Park, back country elk moved away from humans at distances of 400 m, while those living in the front country tolerated significantly closer approaches by people on foot (15360, 12310).

Carnivores may also be disrupted by human activity on trails, pipelines, and seismic lines. Cougars do not appear to avoid trail rights-of-way and old seismic lines in the Sheep River drainage of southwestern Alberta (P.I. Ross and M.G. Jalkotzy, unpublished data). However, cougars on kills may shift feeding times to nocturnal periods to avoid human disturbance on nearby trails (50). Wolverines appear to be very sensitive to disturbance at natal den sites and will move new-born young if disturbed (94593, 951484). Natal den sites have been located in secluded high-elevation cirque basins, and these areas may be frequented by snowmobilers and crosscountry skiers (94593).

Habitat avoidance may occur in the vicinity of trails, cutlines, and seismic lines, although wildlife appears to avoid these smaller disturbance corridors less than roads. Grizzly bears and black bears avoided habitats within 274 m of trails generally, and within 883 m in high use areas (20). Forest-dwelling carnivores may avoid habitats lacking overhead cover (e.g., marten [411]), but pipelines, seismic lines, and trails appear to be narrow enough to preclude any significant avoidance effects (e.g., 951544). Bobcats did not avoid areas with trails for their home ranges in Wisconsin (660). River otters did not demonstrate significant avoidance of pipelines and seismic lines in an area closed to public travel in northeastern Alberta (950767).

Ungulate avoidance of habitat in the vicinity of trails is variable. In southwestern Alberta, elk avoided habitat within 100 m of pipelines in spring, summer, and winter, and habitat within 300 m in fall (860). However, elk did not avoid seismic lines and cutlines in the same study. Deer avoidance of habitat around these linear developments appear similar to that of elk. In 1 case, avoidance appeared to be related to the availability of habitat. In an area where suitable habitat was available away from tracks used by hikers, 4-wheel-drives, and motorcycles, deer avoided the disturbance corridor (11010). However, if habitat was available only in the immediate vicinity of the corridor, that habitat was used. Barren-ground caribou with calves avoid the TransAlaska Pipeline corridor (3930, 3960); however, a road is associated with this disturbance corridor. Disturbance corridors in northeastern Alberta, including pipelines and seismic lines, were avoided by woodland caribou (950587). Moose avoided seismic lines during periods of seismic activity in northwestern Alberta (19210). Conversely, moose did not avoid the TransAlaska Pipeline corridor (600) or a pipeline corridor in westcentral Alberta 1 year after its construction (3140). In Elk Island National Park, the proportion of moose within

500 m of crosscountry ski trails decreased from that recorded prior to trail development (3390).

Barrier and filter effects of trails, pipelines, and seismic lines have been demonstrated in some cases (e.g., marten [94583, 94573]). In particular, pipelines under construction may be significant filters to ungulate movement. Elk, moose, and deer had difficulties crossing when welded pipe strings were left above ground on blocks prior to burial (e.g., 3110, 3130, 3140, 19220, 7090). The ability of different species of ungulates to cross pipelines under construction was related to their size and the size and number of pipes, berms, and trenches involved in the construction. Multiple pipes, and pipes lying adjacent to trenches and berms tended to decrease crossing rates. Visibility across the right-of-way appeared to be 1 of the major factors affecting the willingness of all ungulates to cross these disturbances (e.g., 3140). In contrast, the elevated TransAlaska Pipeline was not a filter or barrier to the Nelchina caribou herd during its migration (13670). Most migratory moose were also successful in crossing that pipeline (7090). Snow depths may play an important role in determining crossing success rates under elevated pipelines since crossing success is related to the ground clearance of the pipeline. Deep snow could reduce crossing success by reducing ground clearances (e.g., 19220).

Habitat disruption or enhancement occurs along pipelines and seismic lines. As it did with roads, the extent of disruption or enhancement depends principally on the width of the disturbance corridor. In an oil and gas development area in northwestern Alberta, there were 2.08 km of linear development per km^2 (950787). Although these corridors accounted for 13,900 ha of land, they represented just 2% of the study area. As was the case with roads, the effect of habitat disruption on wildlife is probably small when compared with the effects of habitat avoidance. Habitat enhancement effects are principally related to increases in forage for ungulates and bears (e.g., 94583, 4180, 2600, 2920), and use of these disturbance corridors as travel routes for all wildlife (94583, 950242, 610, 7640, 412). Since these corridors typically have fewer people associated with them, they are probably more important as travel routes to wildlife than are roads.

Direct mortality as a result of trails, pipelines, and seismic lines is probably very rare because of their low use or lack of use by high-speed motor vehicles; no references to direct mortality were found as a result of these disturbance corridors.

Indirect mortality sources related to trails, pipelines, and seismic lines are similar to those of roads. Human access results in increased mortality (e.g., hunting [19260, 10470, 951564, 4700, 905], trapping [3600, 950964, 4870, 15040, 6640], poaching [70, 750357]). Management actions probably also increase with the presence of trails and humans associated with them. Extensive snowmobile trails through caribou winter range provide an easy means of travel for wolves (950242), and if these trails allow wolves access to previously inaccessible caribou, wolf predation on those caribou may increase (610). Snowmobile harassment may indirectly cause caribou mortality if caribou are forced into suboptimal habitat where risks of accidental deaths are high (e.g., avalanches [11340]). In addition, the disturbance corridor may also result in increased predation by a variety of nest predators for interior-forest birds breeding along the corridor (e.g., 13900).

6.3 Railways

The effects of railways and railway rights-of-way are different and likely less disruptive to wildlife than roads, although studies of their effects on wildlife beyond direct mortality are few. Human activity on the railway right-of-way is minimal relative to roads, pipelines, and seismic lines, although the railroad right-of-way may be used for hunting access in some areas. In addition, human disturbance is predictable and generally does not involve humans outside of the train, further reducing the likelihood of significant disturbances. **Individual disruption** is not likely to occur very frequently for this reason. A grizzly bear foraging along a railroad right-of-way yielded to train traffic at the last possible moment and returned soon after the train passed (M.G. Jalkotzy, pers. observation). Again because human presence on the railway right-of-way is both uncommon and predictable, **habitat avoidance** likely does not occur. Similarly, railroads probably do not act as barriers to most large mammals, although small mammals (e.g., microtines) may be affected. Wildlife habitat is lost under the railroad bed resulting in **habitat disruption** along the right-of-way. **Habitat enhancement** also occurs for some wildlife species. The railroad may be used as a travel route (wolves [280], moose [5330, 951644], grizzly bear [M.G. Jalkotzy, pers. observation]), and the right-of-way may also be a preferred foraging habitat for ungulates and bears in forested landscapes. The railway right-of-way may also be used more than expected by certain scavengers and carnivores since carrion and small mammal populations may be concentrated along the corridor (e.g., wolverine, coyotes, owls [951644]). **Direct mortality** on the railway has been documented frequently in the literature. Most large ungulates species found in Canada's mountain parks are killed on the Canadian Pacific railway (3850, 951644). Less well documented are the many medium-sized and small mammals, and birds that are also killed (951644). The number of wildlife-train collisions for most species is poorly documented with the exception of a report on train-caused mortality on the Canadian Pacific railway between Revelstoke and Field, B.C. by a railway engineer, P. Wells (951644). Since the extent of kill has not been adequately documented, it follows that the importance of train-caused mortality for local wildlife populations is unknown. **Indirect mortality** as a result of the railway has not been documented, although increased human access as a result of the railway right-of-way would increase man-caused mortality along the disturbance corridor. In addition, if wildlife use of the railway results in increased levels of habituation to humans, then the effects will be more detrimental. Grain spillage from rail cars is an example of this. Bears, both grizzlies and blacks, are attracted to this food source (M. Jalkotzy, pers. observation). Since feeding on grain along the railway likely increases a bear's habituation to humans, bears are then more likely to die from human-related causes. The disturbance corridor may also result in increased predation by a variety of nest predators for interior-forest birds breeding along the right-of-way (e.g., 18270, 16910, 13900).

6.4 Powerlines

Disturbance related to powerlines and their rights-of way have aspects that are similar to trails, seismic line, and pipeline corridors in that the rights-of-way allow access for humans. They also have unique disturbance effects because of the presence of the powerline.

Disturbance of birds, particularly nesting raptors, has been documented along powerline corridors. Many raptors nest on powerline support structures (see habitat enhancement, below), and these birds are subject to **individual disruption** (e.g., osprey [16040], ravens, golden eagles, ferruginous hawks [18120], red-tailed hawks [15680]. Power poles are also frequently used for resting, roosting, and hunting (8050, 16060, 12142), and birds using them may also be disturbed. Responses to human disturbance is species-specific. Large birds appear to be more affected by human disturbance than smaller birds. Among raptors, certain species appear to have lower tolerances than others (e.g., ferruginous hawks [951504] vs. red-tailed hawks [951384]). Responses to human disturbance may also be influenced by hatching chronology (19180). Incubating birds are more likely to abandon nests (e.g., 951504). Once eggs have hatched, the likelihood of nest abandonment declines. When birds are disturbed at nest sites, parental care of young may be affected. Decreased feeding of hatchlings has been documented (e.g., bald eagles [1850]). **Habitat avoidance** relative to powerline corridors has not been well-documented. However, when an open corridor, like a transmission line right-of-way, is cut through a forested area, interior forest-dwelling birds avoid the disturbance corridor and forested habitats along its edge (e.g., 14670). In addition, any use of a powerline right-of-way by humans will increase avoidance of habitats in the vicinity by large mammals. **Habitat disruption or enhancement** may occur along the powerline right-of-way for some wildlife species. Interior-forest dwelling bird lose habitat to the right-of-way, while habitat generalists, and mixed habitat or early-successional species may increase in number (14160, 13330, 4830). Habitat enhancement for large mammals are similar to pipelines and relate to the increase in forage plants for ungulates and bears, and the use of the corridor as a travel route for most wildlife with large home areas. Medium-sized carnivores like coyotes and lynx may also be attracted to the right-of-way because of increased densities of rodents and other prey. Support structures for transmission lines provide nesting platforms for raptors and ravens (16040, 18120, 15680, 16060).

Electrocutions and collisions with transmission lines are 2 sources of **direct mortality** associated with powerline corridors (870). Bevanger (16070) conducted a review of these mortality sources. More collisions occurred during migration than at other times and problem areas frequently were located over water or other open areas. Larger birds collided with transmission lines more frequently (e.g., cranes [18450]) than small birds. Large birds were also more likely to be electrocuted than small birds and this can lead to sex-biased mortality in bird species like raptors where females are larger than males (e.g., 8050). **Indirect mortality** along powerline rights-of-way occur as a result of changes in access. As was the case with other development corridors, increased human access along the corridor may lead to increased hunting, trapping, and poaching mortalities. In addition, birds nesting along the right-of-way and in forest bordering the corridor suffer increased predation at nest sites by mammalian and avian predators (e.g., 9620, 13900, 17610). The rate of parasitism by brown-headed cowbirds on bird nests along the corridor also increases (e.g., 13900).

7.0 Species/Group Summaries

7.1 Grizzly Bear

Grizzly bears may be vulnerable to **individual disruption** arising from construction, maintenance, and use of linear developments. Efficient foraging strategies of bears were disrupted near human facilities including roads in Yellowstone National Park (960). Archibald et al. (16) documented, between prehauling and posthauling, a 33% and 39% reduction, respectively, in the number of times that 2 bears crossed a logging road in the Kimsquit Valley in British Columbia. These bears did not appear to habituate to logging traffic after 2 years of hauling. However, many authors, (e.g., 950094, 950098, 30, 950096) believed that grizzly bears may become accustomed to predictable occurrences, including traffic. Habituation may permit some bears to exploit habitats adjacent to roads and other developed corridors. However, it may also greatly increase the likelihood of negative bear-human interactions, with the attendant risk of management action to remove problem bears. Another factor likely to influence bears' responses to human activity is whether or not bears are hunted. Hunted bear populations do not have habituated bears.

Linear developments may result in **habitat avoidance** for grizzly bears. Logging-truck traffic in the Kimsquit Valley in British Columbia resulted in a 78% reduction in use of the "Zone of Hauling Activity" by radiocollared bears compared to non-hauling periods (16). For 14 hours/day, 3%-23% of each bear's home range was unavailable to them because of disturbance. Because bears used these areas when hauling was not going on, it was clear that these areas were important to the bears. In rich habitats such as coastal B.C., where bear home ranges are small, these losses can limit access to important food sources.

In Banff, Yoho, and Kootenay National Parks, 335 km² of available habitat experienced human-use levels exceeding the tolerance of non-habituated bears (950095) and were thus unavailable to those bears. In southeastern British Columbia, McLellan and Mace (950098) calculated that 8.5% of their total study area was effectively lost to bears as a result of road avoidance. Mattson et al. (960) estimated that habitat effectiveness lost to developments was sufficient to support 4-5 adult female grizzly bears in their study in Yellowstone National Park. Grizzly bears also avoided areas adjacent to roads in Denali National Park and Montana, respectively (950094, 3780).

On the Rocky Mountain Front in Montana, Aune et al. (950097) reported that for all monitored bears, "In spring and fall the 0-500 m distance to road category was used significantly less than expected. All other categories were used as much as expected when compared to random chance. In summer this distance category was used as much as expected. Results imply that in summer for all grizzlies sampled, road influence zone could be less than 500 m but during spring and fall may be at least 500 m.” (pg. 59). Road-habituated bears “showed no significant road avoidance in spring or summer in the 0-500 m category. However (they) did significantly avoid this zone in fall. It appears that any road influence on these bears would be less than 500 meters from the roadside for spring and summer.” (pg. 62). Bears which were classed as non-habituated to roads within their home ranges “showed significant avoidance of the 0-500 meter road category for all three season(s) and for fall the avoidance was significant to 1,000 meters of the roads.” (pg. 62). Similar avoidance of habitats within 500 m of roads was demonstrated by bears in the Pine Butte Preserve, Montana (247). In northwestern Montana, grizzlies used habitats within 914 m of roads at just 20% of the predicted rate, and used areas >1,860 m from roads more than predicted (20).

The relationship between grizzly bears and roads may be strongly influenced by the habitat types through which the roads pass. In the Swan Mountains of northwestern Montana, grizzly bear avoidance of roadside buffers generally increased with traffic levels and road densities, but bears did use important habitats adjacent to roads with low to moderate traffic levels (882).

Other authors who have identified displacement of grizzly bears from habitats adjacent to linear developments include Elgmork (444), Mattson et al. (960), Weber (890), Craighead et al. (18710), and reviews by Schallenberger (88) and Schoen (1950). However, in some cases, little displacement from industrial activity was demonstrated (26). In this last study, bears encountered in open habitats showed stronger reactions to disturbance than those encountered in cover. Weaver et al. (950101) also recognized the role of cover in mediating disturbance effects on grizzly bears.

Weaver et al. (950101) generated a cumulative effects model for grizzly bear management, incorporating habitat, displacement, and mortality submodels. The displacement and mortality submodels relate directly to the effects of linear developments. Human activities were classified as motorized or nonmotorized, and as linear, point, or dispersed in nature. Intensity of disturbance was classified as high or low use, and day or overnight use. An experienced team of grizzly bear researchers subjectively estimated disturbance coefficients and zones of influence for each disturbance type. The zone of influence identifies the distance out to which bears would be affected by the activity. Disturbance coefficients, on a scale of 0.0 to 1.0, reflect the degree of disturbance within the zone of influence; lower values identify stronger disturbance effects. The presence or absence of cover (vegetation adequate to hide 90% of a standing adult bear from human view at ≤60 m) was considered important in mediating both the zones of influence and coefficients of disturbance. A summary of disturbance effects associated with linear developments is presented in Table 1. All of the listed linear and point activity types are or could be associated with roads or other linear developments. Dispersed activities are included in the table for comparative purposes. Herrero and Herrero (60) used the same cumulative effects model to predict the effects of a proposed open coal pit mine in west central Alberta.

Seasonal variation in displacement effects on grizzly bears was observed in several studies. On the Rocky Mountain Front in Montana, Aune et al. (950097) found that all bears avoided roads most prominently during fall. This may be habitat-related (important pine-nut habitats tended to be remote from roads), or may be related to increased traffic levels and other activities during big-game hunting seasons. Aune (455) later reported that the mean distance to roads increased from spring to summer and from summer to fall. Mattson et al. (960) reported that grizzlies in Yellowstone tended to avoid habitat within 500 m of roads during spring and summer, and that during fall they avoided areas within 3 km of roads. In southeastern British Columbia, avoidance of areas close to roads was slightly greater in spring than in summer/fall (950098). In northwestern Montana, Kasworm and Manley (20) differentiated only spring and fall seasons, and found no difference in displacement effects. In the Swan Mountains of Montana, grizzlies were more closely associated with higher total road densities during spring than during summer or fall (882). If traffic volumes and other variables remain constant, it seems likely that

Table 1. Zones of influence (ZI) and disturbance coefficients (DC) for cover and noncover areas by activity group, for a grizzly bear cumulative effects analysis displacement submodel (from 950101). The zone of influence identifies the distance out to which bears would be affected by the activity. Disturbance coefficients reflect the degree of disturbance within the zone of influence; lower values identify stronger disturbance effects.

Activity group	Cover		Noncover	
	ZI	DC	ZI	DC
Motorized Linear, high use	ridge line, 0.8 km	0.7	ridge line, 3.2 km	0.6
Motorized Linear, low use	ridge line, 0.8 km	0.9	ridge line, 3.2 km	0.8
Motorized Point, diurnal high intensity	ridge line, 1.6 km	0.5	ridge line, 3.2 km	0.4
Motorized Point, diurnal low intensity	ridge line, 1.6 km	0.7	ridge line, 3.2 km	0.6
Motorized Point, 24-hour	ridge line, 1.6 km	0.2	ridge line, 3.2 km	0.1
Motorized Dispersed	N/A	0.5	N/A	0.4
Nonmotorized Linear, high use	0.2 km	0.8	line-of-sight, 0.8 km	0.7
Nonmotorized Linear, low use	none	1.0	line-of-sight, 0.8 km	0.9
Nonmotorized Point, diurnal	0.5 km	0.8	line-of-sight, 0.8 km	0.5
Nonmotorized Point, 24-hour	0.5 km	0.5	line-of-sight, 0.8 km	0.3
Nonmotorized Dispersed, high use	N/A	0.8	N/A	0.7
Nonmotorized Dispersed, low use	N/A	1.0	N/A	0.9

any observed seasonal variation in habitat displacement for grizzly bears would be related to seasonal changes in habitat importance, arising, for example, from progression of plant phenology.

During winter (roughly November 15 to April 1; [18760]), nearly all grizzly bears are in dens. Bears may be displaced from their dens by intensive industrial activity (1490). Bears which flee their dens during winter will likely experience severe physiological stress and may die, and abandoned cubs will not survive (251). However, bears may be relatively tolerant of disturbance when in their dens. Reynolds et al. (5710) found that no bears deserted their dens despite seismic activity within 800 m and, in 1 instance, the passage of a supply train within 100 m. The danger of winter industrial operations within grizzly bear denning areas is that precise locations of dens will not be known, and new construction or other activities may inadvertently approach them very closely.

Diurnal variation in grizzly bear responses to roads has also been investigated. McLellan and Mace (950098) found no difference between day and night distances that bears were located from roads. However, they, and Zager (12210) and Aune and Stivers (247) reported that bears were more likely to be found directly on roads during night.

Ruediger (18810) hypothesized that net impact on carnivores increases with construction standard of roads. High-speed, high volume interstate highways probably have a greater impact on carnivore populations than do small rural roads. Intuitively, heavily-used roads probably have a larger negative effect on grizzly bears than quieter roads. Gibeau and Heuer (300) reported that female grizzly bears which would not cross the TransCanada Highway within the Bow River valley would cross other 2-lane highways. In Denali National Park, increasing numbers of vehicles near grizzlies provoked larger responses by bears (9320). In northwestern Montana, the number of grizzlies showing selection for 500 m buffers surrounding roads decreased as traffic volume increased (882). All bears in this study avoided buffers around roads with >60 vehicle passes per day, and most avoided buffers around roads with >10 vehicle passes per day, but there was some selection, or neutrality, for buffers surrounding roads with ≤10 vehicle passes per day. Kasworm and Manley (20) monitored grizzly bear movements relative to a seasonally closed road in northwestern Montana. The mean distance from bear radio locations to the road increased from 655 m before the road was opened to 1,122 m after it was opened to public use.

Another consideration, however, is habituation. Habituation may be an individual behaviour (9320), and some bears may never habituate to traffic. Presumably, all bears are unlikely to habituate to infrequent traffic, and may react more vigorously to once-per-week vehicle passages than to vehicles passing every few minutes. Similarly, regular spacing of vehicles is likely to contribute more toward habituation than the same volume of traffic concentrated in a brief period. Habituation may allow bears to continue to use desired habitats near roadsides. However, because of its likelihood of contributing to negative bear-human interactions, habituation in general should not be considered beneficial to bears (18760).

Trails include foot, bicycle, and equestrian trails, and may include roads that are closed to public use. Trails used by motorized off-highway vehicles are presumed to have the same effects on grizzly bears as roads. In northwest Montana, grizzlies avoided habitats within

274 m of trails (20). Overall, trails displaced grizzly bears less than roads did in this study. In the Swan Mountains, Montana, grizzlies were found significantly further than expected from trails during spring, summer, and autumn (883). These authors concluded that grizzly bears using the hiking area have become negatively conditioned to human activity occurring within and outside the area, and that they minimized their interaction with recreationalists by spatially avoiding high use areas.

Roads and other linear developments may serve either as filters or barriers to the movements of grizzly bears. A highway appeared to exert short-term deflections on movements by 3 bears, all adult females, in Alaska (4460). Smith (950265) also described avoidance of roads by females and family groups. Avoidance of road surfaces by female bears accompanied by dependent young may be a function of their heightened security requirements at these times. Woods and Munro (18890) suggested that some grizzlies seemed reluctant to cross the TransCanada Highway in British Columbia. Gibeau and Heuer (300) reported that for 2 years, no radiocollared female grizzly ever crossed the TransCanada Highway in Banff National Park. In Slovenia, a highway served as a home range boundary for 3 radiomonitored adult brown (grizzly) bears (19050). These bears approached the highway, closely at times, but the 2 females did not cross it and the male crossed it only twice.

No absolute threshold has been determined to define a road density which is acceptable to grizzly bears. In the Swan Mountains of northwestern Montana, a total road density (including closed and rarely-used roads) of <6.0 km/km^2 differentiated areas which were used and unused by grizzly bears (882). At some density, roads will become complete barriers or mortality sinks to grizzlies (18810), even if adjacent habitats would support their populations. However, it is difficult to predict the consequences of any particular road density on a bear population since many factors such as habitat, road type, and traffic volumes also affect the degree to which bears avoid roads.

Effort has been made to standardize allowable road densities in grizzly bear recovery zones. At present, these range from 0.75 mi. open road/mi^2 (0.47 km/km^2) to 1.0 mi. open road per mi^2 (0.62 km/km^2) (18760). The Gallatin National Forest in Montana has adopted an open road density standard of 0.5 mi./mi^2 (0.31 km/km^2) (Noss 1992; cited in 250). It should be noted that the definition of "open roads" *includes* roads which are closed to public users but which are subject to administrative use exceeding "…one or two periods that together … exceed 14 days during the time bears are out of the den (usually between April 1 and November 15)" (18760:148).

Not all authors agree with these standards. Craighead et al. (18710) argue that these densities are much too liberal. They advocate, for grizzly bear recovery and conservation, an open road density no higher than 1.0 km per 6.4 km^2 (0.16 km/km^2; 0.25 mi/mi^2).

They further recommend that roads on federal or state land that exceed this density be closed and obliterated.

Social disruption of grizzly bear populations resulting from linear developments has also been reported. Most records of habitat avoidance (see above) probably also represent cases of social disruption because displaced bears are forced into concentrations higher than those they might naturally seek. If different cohorts of bears demonstrate different tolerance for disturbance, then the resulting spatial arrangement of bears may also be suboptimal. Subordinate cohorts of bears were displaced into poorer-quality habitats near developments by more dominant classes, particularly adult males, in Yellowstone National Park (960). McLellan and Shackleton (29) also determined that adult males used remote areas whereas adult females and some subadults used areas closer to roads. Conversely, Zager (12210) reported that female grizzlies and females with cubs avoided habitats within 200 m of roads, while males appeared to prefer these areas, possibly for travel corridors.

Grizzly bear **habitat** may be **disrupted** by industrial developments, including roads and pipelines. There is, obviously, a direct and complete loss of habitat associated with the structure of a road or other linear development. Soil and vegetation disturbance during construction of roads may reduce habitat quality (528, 12210). Disturbances to permafrost habitats may alter vegetative communities for many years, and thus reduce grizzly bear habitat quality (950250). Intensive vegetation management on hydroelectric rights-of-way may also reduce habitat quality (950250). As with roads, trails involve physical alteration of bear habitat, although the relatively narrow width of most trails means that less habitat is directly affected than by roads.

Not all habitat alterations related to linear developments will reduce habitat quality for grizzly bears (**habitat enhancement**). Grizzlies in the Swan Hills area of Alberta used reseeded vegetation, particularly sweet clover, on road and pipeline rights-of-way quite heavily in fall (526). Snow removal, road dust, and altered drainage patterns along roadsides may cause vegetation green-up to occur earlier than in undisturbed areas, with potential advantages for foraging bears (950094).

Roads and other linear developments may serve as travel corridors for grizzlies. Smith (950265) reported that bears may use unpaved secondary roads as travel routes, as did Zager (12210). Use of roads as travel corridors may increase during darkness (29), presumably because of reduced traffic volumes, increased security, or both. Probably because of the relative ease of walking, combined with the relatively low level of human disturbance, bears may use trails as travel routes more so than roads, especially at night (265). Use of roads as travel routes may lead bears into developed areas with increased risk of negative interactions with humans.

Many authors have reported **direct mortality** in grizzly bear populations as a consequence of linear developments. Grizzly bears may be killed in collisions with vehicles (300; review in 950102). Gunson (950248) analyzed records of 798 grizzly bear mortalities on Provincial lands in Alberta from 1972 to 1994; 5 bears were killed by trains, and 4 by other vehicles. Grizzly bears have also been killed by trains after being attracted to grain spill sites (18760). In Croatia, at least 72 brown (grizzly) bears were killed by cars (*n*=21) or trains (*n*=51) between 1963 and 1994 (950266). Trails do not contribute directly to grizzly bear mortality as highway traffic may. Most authors, however, concur that greater mortality effects arise out of indirect consequences of the construction of roads and other linear developments.

Linear developments like roads generally lead to increased **indirect mortality** for grizzlies. In Yellowstone National Park, adult females and subadults living close to developments including roads were management-trapped at a higher rate than similar animals living in more remote areas (960). Between 1975 and 1990, habituated, radiomarked bears were killed 3.1 times more often than wary radiomarked bears in the Greater Yellowstone Ecosystem (960). Most habituated subadults were killed. Mattson et al. (18801) reviewed grizzly bear mortality in the Greater Yellowstone Ecosystem in 1996. A disproportionate 68% of all mortality occurred in habitat substantially impacted by humans yet this habitat represented 33% of the total habitat available to grizzly bears. Mortality in these impacted habitats was 5.8 and 11 times greater than the lowest rates in United States Forest Service roadless areas and United States Parks Service backcountry, respectively (18801). Many other authors have identified shooting mortality in grizzly bear populations that was related to roads or other industrial access (e.g., 1594, 898, 1928). In Montana, 32% of hunting mortality and 48% of non-hunting mortality occurred within 1.0 mile (1.6 km) of a road (6340). On the East Front of the Rockies in Montana, Aune and Kasworm (950263) reported that 63% of all known human-caused mortalities occurred within 1.0 km of roads. Of 11 known grizzly bear mortalities in a study in southeastern British Columbia, 7 bears were shot from roads and an additional 2 may have been poached from roads (950098). All 8 human-caused mortalities in a study in northwestern Montana resulted from road access and illegal killing or management-related removals (882). In an Alberta study, 75% of all bear mortalities occurred within 1 km of all weather roads (951614). Locations of hunting mortalities on Chichagof Island, Alaska were strongly correlated with road densities as road densities increased (951004).

Indirect mortality as a result of linear developments may occur in other forms. Mattson et al. (960:271) stated "…that avoidance of roads and developments by grizzly bears in Yellowstone Park probably resulted in poorer condition adult females and, consequently, higher mortality rates and lower fecundity for the cohort." Aune (455) speculated that increasing road densities on the relatively-unroaded Rocky Mountain Front could displace grizzly bears. As mentioned above, Gibeau and Heuer (300) reported that for 2 years, radiocollared female grizzlies never crossed the TransCanada Highway in Banff National

Park, and raised concerns about resultant effects on genetic diversity within this population. Adult bears rarely crossed a highway in Slovenia, and inbreeding is a concern in this small population of bears (19050). Reduced litter sizes and other indicators of inbreeding depression have been reported for inbred, captive brown (grizzly) bears (950271).

Shank (9230) pointed out that to be of significant concern to wildlife managers, behavioural responses to disturbance must have demonstrable **demographic consequences**; demographic consequences don't necessarily follow even from significant behavioural responses. Conversely, population effects may occur even though no behavioural response to disturbance was detected. Direct mortalities, whether related to linear developments or not, obviously have population effects on bears. Aside from direct mortality, disturbance effects on grizzly bear *populations* are difficult to confirm and quantify. However, in the Swan Mountains of Montana, Mace et al. (882) concluded that grizzly bear mortality associated with road access and unnatural food sources, in conjunction with natural mortality, inhibited population growth in the local grizzly bear population (882). Similarly, in Yellowstone grizzlies probably suffered significant demographic consequences as a result of indirect mortality (951624).

The U.S. Fish and Wildlife Service (18760) believes that “roads probably pose the most imminent threat to grizzly habitat today” (pg. 21), and that “the management of roads is the most powerful tool available to balance the needs of bears and all other wildlife with the activities of humans” (pg. 145). Although direct mortality of grizzly bears from roads has been documented, the most important effects of roads on grizzly bears are (1) loss of habitat effectiveness because of bears avoiding the disturbance associated with roads, and (2) shooting mortality facilitated by the development of new access routes for hunters and others with firearms.

7.2 Black Bear

In ways very similar to grizzly bears, black bears are subject to the same realm of effects from linear developments. Many of the effects and considerations described for the grizzly bear (see above) are directly applicable to black bears, and will not be repeated here. Largely because the conservation status of black bears is more secure than it is for grizzly bears, fewer research reports describing road effects on western black bears are available. In some regions, such as the southeastern U.S., black bears have received research attention regarding effects of developments, and specific results are available for these areas.

Habitat avoidance may be exhibited by black bears adjacent to roads and other developments because of the human activity concentrated on them. Aune (455) reported that black bears avoided areas within 100 m of any open road. The mean distance to open roads for black bears increased as the seasons progressed. Female black bears in Arkansas used habitats within 240 m of roads less than expected (17990); males were not studied. Black bears in northwestern Montana avoided areas within 274 m of roads during spring, and avoided areas within 914 m of roads during fall (20). Pooling all annual bear locations in this study, females were found to avoid areas within 914 m of roads, while males did not. Conversely, Holcroft (950270) found no difference in distance-to-roads between bear telemetry and sign points and random points in southwestern Alberta.

Trails may also affect black bear use of an area. During spring, bears in northwestern Montana avoided areas within 274 m of trails, and during fall they avoided areas within 914 m of trails (20). Black bears in Rocky Mountain National Park, Colorado, avoided sites of human activity, such as campgrounds and trail heads (1340).

Busy roadways may serve as filters or barriers to movements by black bears. Beringer et al. (32) examined the reactions of black bears to roads in North Carolina. Bears crossed high-use roads less frequently than low-use roads. Similarly, Brandenburg (840) reported that bears crossed primary roads less frequently than secondary (unpaved) roads. Home range boundaries of several female bears in Michigan were defined by major highways, suggesting the roads restricted bear movements (7640). In North Carolina, Brody and Pelton (419) found that bears crossed roads at a lower frequency as traffic volumes increased. They also reported that few bears crossed an Interstate highway. In Florida, an Interstate highway appeared to serve as a barrier to black bears (950093). Bears used highway underpasses mainly to access portions of their home ranges separated by the highway.

Barrier effects may be temporally influenced. In North Carolina, Brandenburg (840) documented only 2 primary road crossings between 1100 hrs. and sunset. Bears preferred to cross primary highways at night and/or during times of low traffic volume. Additionally, Brandenburg (840) reported that frequency of road crossings peaked in early summer and early fall.

Black bears in some areas appear to be relatively tolerant of industrial disturbance during the denning period. Oil development activities near Cold Lake, Alberta, apparently did not deter bears from denning in the vicinity (4700). Manville (4890, 7640) reported that 2 females denned within 100 m of actively-used snowmobile trails, and 2 males denned within 500 m of active oil wells in Michigan. However, black bears can be displaced from their dens by disruptive intrusions. Manville (7640) reported that bears frequently fled their dens upon close approach. Three of 5 cases of den abandonment in Montana were attributed to human disturbance (2400).

The threshold level of road density in black bear ranges is unknown (840). Brody and Pelton (419) suggested that at low road densities, bears were able to adjust movement patterns to minimize risks associated with traffic. They also believed that when road densities reached certain thresholds, bears shifted their home ranges to avoid areas with high road densities. Beringer et al. (32) found that bears strongly avoided high-use roads (multi-lane Interstate highways) as the density of these roads increased within their home ranges. However, bear crossings of low-use roads (single-lane gravel) increased as road density increased. Brody (950274) believed that roads in North Carolina interfered with black bear use of habitat when open-road densities exceeded 1.25 km/km², and when logging-road densities exceeded 0.5 km/km². Hillman and Yow (950275) recommended that road densities not exceed 0.25 km/km² for black bears. This recommendation regarded only the control of human access as a means of limiting illegal hunting; it did not address the issues of habitat displacement or vehicle mortality which, presumably, are at least partly additive to illegal hunting and to each other.

Construction of roads, pipelines, powerlines, and other linear developments normally generates some degree of **habitat disruption**, at least temporarily. The potential negative effects described for grizzly bears (above) also apply to black bear habitat. Significantly, however, **habitat** may be **enhanced** (again, at least temporarily) for black bears. Nagy and Russell (526) documented the importance to black bears of seeded crops used to revegetate road and pipeline rights-of-way in Alberta. They speculated that this habitat manipulation contributed to range expansion by black bears in this area. Manville (7690) also reported that black bears benefited from early-successional vegetation induced by roadside cutting and pipeline construction. The effects of habitat enhancement, however, may be offset by increased mortality if access control is not invoked (see indirect mortality below). In western North Carolina, where timber management could potentially enhance habitat quality for black bears, hunting was found to be a stronger influence on the dynamics of the bear population than was habitat capability (940).

Under certain conditions, road surfaces and pipeline rights-of-way may serve as travel corridors for black bears (7640, 6023, 11220). However, McCutchen (1340) reported that even with national park protection, black bears in Rocky Mountain National Park rarely seemed to use roads or trails as travel corridors. In hunted populations where road access is unrestricted, black bears avoided road surfaces (4980).

Black bears suffer **direct mortalities** as a result of roads and other linear developments. Road kill mortality is reported more frequently for black bears than for grizzlies. This may be because black bear distribution overlaps areas of higher human density and, therefore, more numerous and busier roads. Many authors have reported road kills (e.g., 423, 7640, 419, 950268, 840, 19020). In some cases, road kill mortality may be the largest mortality source (e.g., 2770) and may even threaten the persistence of black bear populations (e.g., 950267). In some cases, black bear highway mortality has been related to artificial food attractions (950267, 300). Pat Wells, a Canadian Pacific railway engineer, documented the deaths of 21 black bears over a 3-year-period on a 198-km-long section of the CPR between Field and Revelstoke, B.C. (951644).

Road access also contributes to increased shooting mortality, legal and illegal, in black bear populations (**indirect mortality**). Brody and Pelton (419) believed that the major effect of roads in black bear habitat in western North Carolina was to increase vulnerability to hunting. In this area, hunters use hounds and drive slowly along roads until the dogs strike a bear scent. Seventy-three percent of bears killed in this area were shot within 1.6 km of a road, and 23% within 70 m of a road (32). Bear hunting in Michigan was also facilitated by road access. Manville (7690) reported that the average distance from a light-duty road to point of harvest for 9 marked bears was 0.46 km. Tietje and Ruff (4700) felt that the secondary effects of industrial activities, including development of new roads, increased bear hunting, and human habituation, would have greater negative impacts on a black bear population in northeastern Alberta than would the primary effects of habitat alteration and loss.

Mortality associated with linear developments may result in **population effects**. In a small, isolated black bear population in North Carolina, a high-speed highway density averaging 0.33 km/km^2 produced enough road kills to threaten to extirpate the population (840). R. Serroya, a researcher in Banff National Park, estimated that there are about 20 adult black bears in the Bow Valley and in 1996, 6 mortalities were recorded (951634). Four mortalities occurred on the TransCanada Highway and 1 on the railway and he speculated that the Bow Valley was likely a population sink for black bears. Gibeau and Heuer (300) reported that highway and railway kills accounted for an average of 9-11% of the Banff National Park black bear population each year between 1985 and 1995.

7.3 Wolf

Wolves are sensitive to the presence and human use of linear developments. Roads may be a major threat to wolf recovery because of barrier effects, vehicle collisions, and other human-caused mortality factors resulting from increased access. (e.g., poaching, hunting) (18780).

Individual disruption has been documented in the immediate vicinity of dens and home sites. Wolves in Alaska abandoned home sites and moved their pups in response to human disturbance in 24% of cases (n=33) when disturbance lasted <1 hour; in 54% of cases (n=13) when disturbance lasted >1 hour but <1 day; and in 100% of cases (n=4) lasting more than 1 day (850). Disturbances in this study included humans on foot, in aircraft, and in vehicles, and occurred at variable distances from the wolves.

Habitat avoidance as a result of linear developments has not been reported for wolves as frequently as for bears. However, it can be inferred from the results of several studies.

Habitat avoidance is, to some extent, a function of the level of disturbance. The response of different wolves to a given disturbance is variable and difficult to predict (850, 280). It may also be influenced by the intensity, duration, and predictability of the disturbance (850). Thurber et al. (18370) determined that wolf absence from heavily-used roads was a result of behavioral avoidance of disturbance, rather than direct attrition. Habitat displacement was presumed, therefore, but the amount was not estimated. Similarly, Paquet and Callaghan (280) reported that high traffic volumes on the TransCanada Highway in the Bow River valley appeared to alienate wolves from areas that they might otherwise use. Including disruption from roads and other linear developments, plus other human structures and activities, wolves were estimated to be displaced from a total of 92 km^2 of montane habitat in the Bow River valley, or 62% of the best wolf habitat in the valley (280).

The research record from central North America is fairly clear in describing the relationship between road density and wolf-population persistence; wolves rarely occupy areas with road densities higher than 0.6 km/km^2. In the more open landscapes of the Rocky Mountains, the relationships between wolf survival/persistence and road density has not been determined (18790). Thiel (9670) reviewed historical data and found that wolves in Wisconsin failed to survive when road densities accessible to 2-wheel-drive vehicles exceeded 0.93 mi/mi^2 (0.58 km/km^2). Telemetry data along the Minnesota-Wisconsin border supported the historical observations. Thiel (9670) felt that wolf habitat management plans should incorporate road density limits which do not exceed 0.93 mi/mi^2 (0.58 km/km^2). In Ontario, road density in areas not occupied by wolves (mean=0.93 km/km^2) was greater than in areas occupied by wolves (mean=0.38 km/km^2) (6830). In the same study, mean road density in Michigan where no wolves reside (0.69-0.84 km/km^2) was also greater than in wolf-occupied areas of Ontario.

Mech et al. (7820) reported that mean road density in that portion of Minnesota occupied by wolves was 0.36 km/km^2. Road density and human density were inversely correlated with viable populations of gray wolves. Densities of roads for the entire range of wolves in Minnesota, the primary range, the peripheral range, and the disjunct range were all below the threshold road density for loss of wolf distribution (0.58 km/km^2) given by Thiel (9670) and Jensen et al. (6830). However, Mech et al. (7820) felt that these results may not apply to areas with different human populations or road use, or roads with restricted public access. In Mech's (9990) study, a low-density wolf population persisted in an area (Superior National Forest) where road density exceeded 0.58 km/km^2 but which was adjacent to an extensive area having fewer roads (Boundary Waters Canoe Area Wilderness). Also in Minnesota, Fuller (1255) found that no wolf-pack territories had road densities >0.72 km/km^2. The density of maintained roads was higher outside of pack territory boundaries than inside (0.59 vs. 0.38 km/km^2).

Fuller et al. (5920) reported on the distribution and numbers of wolves in Minnesota since 1950. "In general, wolves occurred where both road density and human density were low; 88% of packs and 81% of single wolves were in townships with <0.70 km roads/km² and <4 humans/km² or with <0.50 km roads/km² and <8 humans/km²" (pg. 48). They also noted a potential bias towards areas with relatively higher densities of roads and humans because of the higher likelihood of observations being made in these areas.

Finally, Mladenoff et al. (950162), found that mean road density was much lower within pack territories (0.23 km/km²) than in random areas that were unoccupied by wolf packs (0.74 km/km²) in the Great Lakes region. Few pack territories contained areas with a road density >0.45 km/km², and none had a road density >1.0 km/km². Road density was found to be one of the most important predictors in comparing new pack areas in Wisconsin to non-pack areas. This agrees with Jensen et al. (6830), who felt that an evaluation of road densities, in conjunction with other factors, may aid in estimating the impact of development on established wolf populations, or in predicting the likelihood of re-establishing wolves in an area.

High human densities, indicated by road densities of > 0.6 km/km², apparently serve as a barrier to wolf dispersal into Michigan (6830). Mladenoff et al. (950162) reported that fragmentation of favourable wolf habitat along development corridors in northern Wisconsin may be responsible for the slow growth of the wolf population. Wolves apparently move throughout that landscape, crossing many unfavorable areas, but are unlikely to become established except in higher-quality habitats with low road densities.

The TransCanada Highway serves as a filter to the movements of wolves across the Bow River valley in Alberta (280). This has several effects: it impedes the ability of wolves to disperse naturally across their range, and it likely alters territorial movements. Paquet and Callaghan (280) reported that some wolves are more successful than others at using underpasses to cross the TransCanada Highway. Because wolves live in highly-structured social groups, such a "differential sieve" may affect pack members differently and influence, at least temporarily, pack cohesiveness and behaviour.

No references were found which dealt with the direct effects on wolves of **habitat disruption** arising from construction and maintenance of linear developments. If construction degrades or enhances habitat quality for ungulates (i.e., wolf prey), then it can be inferred that an indirect effect would be realized by wolves as well.

Linear developments could be considered **habitat enhancement** since they often serve as travel corridors for wolves, probably more so than for most other large carnivores. Many wolf research studies report that live-trapping efforts are often focused on unused roads to take advantage of wolves' propensity for traveling along them. Thurber et al. (18370) reported that wolves were attracted to unused or rarely-used roads in Alaska because they provided easy travel corridors. Similarly, wolves were attracted to the Trans-Alta powerline and the CP Railway in the Bow Valley and used them as travel corridors, particularly when snow was deep (280).

Thurber et al. (18370) reported on relationships of wolves in Alaska to roads of different types. Oilfield access roads--which received substantial industrial use and which were open to public use all year--were avoided by wolves. Wolves were attracted to a gravel pipeline access road which was gated and closed to vehicles for most of the year. Secondary, gravel roads which were available to the public but were unplowed during winter were also used by wolves. Wolf reaction to a heavily-used, paved highway was ambivalent, possibly because of an active wolf den within 1 km, or possibly because of relatively high prey densities immediately adjacent to the highway.

Preliminary results from the on-going study in northeastern Alberta suggest that linear corridors influence the distribution of wolves. Radio locations of wolves were closer to linear corridors than would be expected by chance (950587). Wolves have been observed to use linear corridors. Edmonds and Bloomfield (950242) noted that extensive snowmobile trails within caribou winter range provided a easy means of travel for wolves, which may have contributed to increased predation on a threatened (now endangered) caribou herd. Once wolves discover packed access routes into previously inaccessible caribou winter range, wolf predation on those caribou will increase (610).

Direct mortality as a result of linear corridors, principally roads, is common with wolves. Perhaps partly because of their propensity for using road surfaces as travel corridors, wolves seem to be rather frequent victims of road kill. Vehicle collisions as a mortality factor in wolf populations have been reported in locales as diverse as Alberta (950232), Idaho (950202), Israel (950182; 15710), Minnesota (2860; 1255), Montana (18810), Ontario (5810; 950222), Wisconsin (950212), and the Greater Yellowstone Ecosystem (950202).

Indirect mortality as a result of linear corridors can be a serious problem. "Roads do not kill wolves--people do" (950212: 174). Roads themselves do not prevent wolves from inhabiting an area. However, the threat is from intentional or accidental killing by humans gaining access. For example, on the Kenai Peninsula in Alaska, 87% of documented wolf mortality was human-caused, and distribution of reported wolf harvest was concentrated along zones of easy human access (905). Although wolves often use corridors as travel routes, the provision of artificial travel corridors need not be construed as a positive development. Paquet and Callaghan (280) were not able to determine whether utility and railroad travel corridors in the Bow Valley were disruptive to wolves, but pointed out that they at least contributed to travel patterns that deviated from those in undisturbed landscapes, and identified that attraction to the railroad corridor contributed to unnatural wolf mortality.

Population effects on wolves are difficult to determine. However, Fuller (1255) concurred with Thiel (9670), Jensen et al. (6830), and Mech et al. (7820) that road densities >0.6-0.8 km/km² provided enough access for humans to limit wolf numbers through legal or illegal trapping or shooting. Highway mortality was a primary mortality factor for recolonizing wolves in Banff National Park, accounting for 34% of deaths between 1986 and 1993 (950232).

7.4 Cougar

The effects of linear developments on cougars have been difficult to determine because of the species secretive nature. However, with the increased use of radio telemetry to monitor cougar movements, some aspects of the effects of human development on cougars are becoming better understood.

Individual disruption of cougars can occur as a result of linear developments. Usually these effects are indirect and are associated with human use of the disturbance corridor rather than the corridor itself. Cougars demonstrated shifts in activity patterns near human disturbance (1990, 9840). In the absence of human disturbance, cougars showed peak activity within 2 hours of sunset and sunrise. Near human developments, cougar activity peaks shifted to after sunset. Other activity was concentrated during night hours, and there was no activity peak at sunrise. Generally cougars bed close to their kills if there is cover available. However, if a kill is near a human disturbance, this may not occur. In summer 1994, a radiocollared female cougar killed a mule deer about 50 m from a frequently-used equestrian and hiking trail (50). Intensive monitoring of this cat showed that she bedded 200-800 m from the carcass during daylight hours and fed on it at night.

Recently independent, young adults in search of home ranges encountered disturbances more frequently than did resident cougars in northern Arizona and in southcentral Utah (1990). This age class are typically searching for areas to settle in and lands vacant of established residents probably occur more frequently in proximity to human development.

Habitat avoidance has been documented in some, but not all, circumstances where cougars are confronted by human developments. Reactions of cougars to logging and other human activities were studied in northern Arizona from 1976 to 1980 and in southcentral Utah from 1979 to 1982 (1990). In this study, resident cougars rarely were found in or near (<1 km) sites logged within the past 6 years. Established residents and young cougars that ultimately became residents selected home areas with road densities lower than the study area average, no recent timber sales, and few or no sites of human residence (1990). Younger (2- or 3-year-old) cougars were found in logged areas more often than older cougars, but 4 of 5 young cougars that visited logged areas did not maintain residence there. Similarly, in a northern Florida introduction project, the area where released cougars reestablished home ranges contained about one-half the density of roads as in the entire study area (951104).

Use of fragmented habitat by a remnant population of cougars in south Florida has been intensively studied (951154). Cougar occupancy became more likely in habitat patches >500 ha, and only 25% of cougar locations occurred in patches smaller than 500 ha. The same data suggested that cougars consistently used larger areas with fewer major highways. However, none of the 8 road variables effectively distinguished cougar radio locations from random points (951154). In south Florida where forest cover exists within an agricultural matrix, cover was most likely to constitute cougar habitat if the forested area was an isthmus, connected to permanently occupied cougar range, or if it was an island within ~100-200 m of a larger forest tract (951154). Bands of forest as narrow as 100 m were used by cougars. In similarly fragmented habitat in southern California, 13 of 18 transient home ranges of dispersing cougars abutted the urban-wildland interface. Eleven of the 13 home ranges had their longest border along that interface, strongly suggesting avoidance of urban areas (14640).

Cougars do not always avoid human activity. In southwestern Alberta, radiocollared cougars were documented in the immediate vicinity of human developments (50). A hard-surface road (SR546) bisected the study area and the winter home ranges of 2 cougars living there. During the summer when it was open, SR546 was busy with vehicles on weekends, but generally less so during the week. There were numerous day-use sites and 3 campgrounds along the road. Typically they were heavily-used on weekends but were vacant during cold, rainy weekdays. Radiocollared cougars did not abandon core home ranges along SR546 in the summer solely to avoid contact with humans. Cougars whose summer home ranges overlapped with a 2-km wide disturbance corridor centred on SR546 did not prefer or avoid corridor land. Human activity in localized areas did not deter radiocollared cougars from entering the immediate vicinity in some cases. In 1 case, a female bedded during the day in a 10-m wide strip of conifers between the Sheep River and SR546 on a very busy weekend. In another case, a radiocollared female traveled down a 50-m wide drainage between 2 busy campgrounds and crossed SR546 after sunrise. Cougars in the Sheep River area appeared to be well-adapted to the level of human disturbance that occurred in there.

Similar movements relative to human developments have been documented in other studies. In New Mexico, the movements of 14 translocated cougars were monitored as part of a larger project (951084). Translocated cougars came close to urban and suburban areas during their movements, possibly because natural travel routes often funneled into towns or cities. An adult male was located within 100 m of houses in the centre of Taos, NM for 1 day where he bedded in dense willow and Russian olive within a riparian area. In southern California, radiocollared cougars were documented traveling alongside housing developments but never for more than 100 m (951114). In the same study area, Beier (14640) found that cougars occasionally bedded 20-100 m from heavily-used trails in dense chaparral during the daytime. Dispersing cougars showed no aversion to parked vehicles and also passed within 30 m of isolated homes and buildings with no outdoor lighting.

Linear developments and associated human disturbances can be filters or barriers to cougar movements. The extent to which roads are filters appears to depend on the size of a roadway and the amount of traffic on it. The effects of roads on cougar movements were examined in Arizona and Utah in 3 study areas (2020). Road crossing frequencies were related to road densities within the home ranges of individual cougars. Unimproved dirt roads were crossed most frequently, while improved dirt roads and hard-surfaced roads were crossed less often. At Sheep River, radiocollared cougars regularly crossed a hard surface road, SR546 (50). Sheep River cougars were most active between late afternoon and early morning and radiocollared cougars crossed roads and trails more often during those times. Track data from Sheep River suggested that road segments that were wider and more open on either side were used less frequently by cougars than narrower segments bordered by cover (951144). Introduced cougars in northern Florida crossed roads frequently (2.7 crossings/cougar day) (951104). However, cougars tended to avoid crossing more heavily-traveled roads (primary hard-surface highways, secondary hard-surface highways, and light duty roads) in favour of more lightly-traveled roads (other roads and trails) within their home ranges. In southwest Florida, only 3 of 13 female cougars radiocollared between December 1979 through May 1991 crossed either SR's 29 or 84 (SR 84 was being upgraded to I-75 at the time; these roads were considered "major" highways by the authors), and only 1 cougar crossed regularly (951054). In New Mexico, movements of translocated cougars were temporarily blocked by towns and highways in some instances. Cougars either changed directions or localized their movements on 1 side of the obstacle for up to 6 months before continuing to move (951084). Ruth et al. (951084) hypothesized that the effects of those manmade obstacles may indicate that naturally-dispersing cougars in the region were also negatively impacted. In southern California, the cougar population on Beier's study area was almost surrounded by urbanization and major transportation corridors impeded the movements of cougars in the landscape (14640). For example, an 8-lane freeway with heavy night traffic precluded crossings by cougars at grade. In this study area, all travel in remnant corridors and habitat peninsulas occurred at night. During overnight monitoring, dispersers usually avoided artificial lights, especially night lights in open terrain.

Cougars can and do cross major transportation corridors. For example, in New Mexico, most of 14 radiocollared translocated cougars crossed several major and secondary highways during their movements after release (951084). Naturally-dispersing cougars in the New Mexico study also crossed many road corridors (951085). During the Sheep River cougar study in southwestern Alberta, radiocollared cougars regularly crossed primary and secondary highways both as dispersing subadults and within home ranges as residents (M. Jalkotzy and P.I. Ross, unpublished data).

In a detailed study of cougar movements relative to human development, Beier examined the use of remnant corridors across major transportation routes in a highly-fragmented cougar population in southern California (14640). He monitored the movements of resident cougars and dispersers relative to 3 remnant corridors (1.5, 4.0, and 6.0 km long) and several habitat peninsulas created by urban growth. Each of the 3 remnant corridors was used by 1-3 dispersers. Five of the 9 dispersers in this study found and successfully used remnant corridors, and 2 dispersers entered but failed to traverse remnant corridors. Dispersing cougars used remnant corridors that were located along natural travel routes, had ample woody cover, included an underpass integrated with roadside fencing at high-speed road crossings, lacked artificial outdoor lighting, and had less than 1 dwelling unit/16 ha. Cougars (dispersers and adults) usually avoided small and large diameter culverts when crossing freeways or rural 2-lane highways. During 5 overnight monitoring sessions, 1 radiocollared cougar crossed a 2-lane road at grade to avoid a culvert. On 2 other overnight monitoring sessions, radiocollared cougars used 1.8 m box culverts to cross 2-lane highways. Beier's data indicate that topography and vegetation (remnant corridor structure) are probably as important as length in determining remnant corridor quality. The location of remnant corridors appears to be critically important. Cougars cross freeways not through the best-designed underpass but through the underpass that is best aligned with a major drainage (14640).

Results which suggest similar behaviour by Canadian cougars have been documented in Banff National Park (951044). In an area along the TransCanada Highway where travel routes were restricted by the highway and mountain topography, cougars had 4 options for travel: 1) a 2-km wide, heavily-forested, north-facing slope characterized by deep snow, 2) a 4-m wide highway underpass on the valley floor that was well-aligned with high-quality habitat, 3) a 190-m wide river underpass that contains the Bow River, a 2-lane highway, and the railway, and 4) a 1-km wide south-facing dry slope of open forest bisected with passable rock outcrops. Based on snow tracking, cougars appeared to prefer the narrow wildlife underpass (8 passages) and the dry south-facing slope (5 passages). Snow tracking in the Bow Valley of Banff National Park identified remnant corridors that cougars used and some that were not (60). The Norquay-Cascade Corridor (a remnant corridor), between 200 m and 800 m wide and about 8 km long, is located between the TransCanada Highway and mountains on the north side of the Bow Valley, and was used by cougars. Cougars using the corridor had to cross both the Minnewanka Road and the Mount Norquay Road. On the other hand, no cougar tracks were found on the narrower Fenland Indian Grounds remnant corridor (<100-300 m, 3 km long) which parallels the above corridor but is sandwiched between the TransCanada Highway and the town of Banff.

Cougars appeared to be adapting to highway underpasses as a means of accessing habitat on both sides of major transportation routes in Florida as well. Cougar use of 4 underpasses on an Interstate-75 was monitored using game counters and cameras for 2, 10, 14, and 16 months between 1989 and 1991. Cameras recorded 10 crossings by cougars (70, 950093). The 10 cougar crossings were by 2 individuals; one crossed once and the other crossed 9 times. Based on radiotelemetry data, cougars crossed exlusively at night and used underpasses mainly for travel between portions of their home ranges separated by the highway. A follow-up study in 1995-1996 indicated that the pattern of wildlife use of the Interstate-75 crossings had not changed, but cougar use of the crossings was substantially greater (950261). This increased use of the Interstate-75 crossings by cougars could reflect acceptance by older established cougars and a "learning curve" by recent additions to the population (950261). In addition, some cougars seemed reluctant to cross these highways without the natural substrates and cover available that now exist in the wildlife crossings. One female cougar, likely born after the wildlife crossings were completed, had a home range bisected by Interstate-75. Cougars also crossed and had home ranges bisected by another major highway, SR29. They crossed using a preformed box culvert (2.4 m high x 7.3 m wide x 14.6 m long), and a concrete and earth bridge over an adjacent canal. Existing highway wildlife underpasses appear to function for cougars in the Bow River Valley (300). However, a lack of use for the years immediately following construction suggests that local cougars required time to accept and use them.

Direct mortality on roads has been documented in many jurisdictions. In 1994, British Columbia's Wildlife Accident Reporting System recorded 4 cougars killed on roads in the province (950797). In British Columbia's East Kootenays, 4 of 7 cougar mortalities recorded during a 2½-year radiotelemetry study were caused by vehicles (951074). Three of the 4 cougars were killed by mine employees driving to or from work. The fourth was killed at night by a mine haul truck. Mine shift changes peaked at crepuscular periods, when cougars were also most active. Mortality sources of cougars were examined from December 1979 through May 1991 in southwest Florida (951054). Roads were the single greatest cause of mortality. Highway collisions caused 46.9% of documented mortality for both radiocollared and unmarked cougars over a 4-year period (1987-90) when annual mortality averaged 17.2%. Another 4 cougars were hit by cars and survived. Since 1990, an additional 11 cougars have been killed by vehicles in south Florida (950261).

Dispersing young cougars may be more susceptible to traffic mortalities because they tend to cross roads more often. In an intensive radiotelemetry study in southern California, 3 of 9 dispersing young cougars died from vehicle collisions (14640). Dispersers recovered from 2 other vehicle accidents in the same study. Of 6 road-killed unmarked females in south Florida, 3 likely were dispersing subadults (951054). In New Mexico, 1 of 14 translocated cougars died as a result of injuries sustained in a collision with a motor vehicle (951084). Resident males may also be more susceptible to traffic mortalities than females since this sex-age class has larger home ranges. Three of the 4 cougars killed in the B.C. study were males (951074).

Seasonal differences in road mortality rates were documented in south Florida (951054). Road mortalities appeared be greater from November to January. This increase during fall and early winter may have been caused by increased traffic associated with tourism.

Cougars may be killed on all types of roads. Beier (14640) documented the deaths of 4 cougars at one crossing point on an Interstate highway in his study area (14640). In south Florida, 6 of 11 cougars killed by vehicles between 1990 and 1996 died on rural county roads (950261).

Linear developments can also lead to **indirect mortality** for cougars. In most western states and provinces cougars are hunted with dogs, and most track searches are conducted from motorized vehicles along linear developments like roads and cutlines. In Alberta the cougar harvest is directly linked to the degree of motorized access that exists in an area (951564). Similarly, houndsmen located and killed disproportionately more cougars along a main road up a drainage than along secondary roads up tributaries in western Montana (951134).

New roads tend to attract human development and human development alongside roads often leads to additional cougar mortalities. In California, the Department of Game and Fish issued 331 permits to kill lions that were preying on pets and livestock in 1995 (951064). One of 9 dispersers in Beier's study in southern California was shot when the cougar followed a habitat peninsula into an urban area (14640).

Population effects are difficult to document. However, the indirect effects of increased hunter access as a result of development may substantially increase cougar mortality in an area. Heavy harvesting maintained over a period of time in a local area may reduce population densities there as well as on adjacent areas because of the lack of young, transient cougars (951754). Local overharvest may have occurred in several Wildlife Management Areas in Alberta prior to the introduction of a quota system (951654).

Fragmentation of habitat may have deleterious consequences for cougar populations if the movement of individuals between habitat patches is eliminated (11760). Beier (11760) simulated the population dynamics of cougars to predict the minimum areas and levels of immigration needed to avoid population extinction caused by demographic and environmental stochasticity for a period of 100 years. Under most plausible parameter values, the model predicted very low extinction risk in areas as small as 2200 km^2, and (in the absence of immigration) increasing risk as the area decreased below 2200 km^2. The model was applied to the cougar population in the Santa Ana Mountain Range of southern California (2070 km^2, with about 20 adults [11760]). Field data supported the model's conclusion that this population was demographically unstable. There was a high risk of extinction if the habitat was reduced to currently protected and connected areas (1114 km²). Remnant corridors between habitat patches must be maintained if these local populations are to persist. Within the Santa Ana Mountain Range, cougars recently became extinct in a 75-km² habitat fragment recently isolated by development (11760).

7.5 Medium-sized Carnivores

In general, there is a paucity of information regarding the effects of linear corridors on most medium-sized carnivores. This discussion deals principally with wolverine, fisher, American marten, lynx, and bobcat. Disturbance-related data for other similar-sized carnivores are mentioned where appropriate. Since data concerning linear developments and these species are few, some of the effects of forestry have been included in the discussion where it was deemed pertinent.

Individual disruption is not well-documented in the literature of this group. However, in the case of **wolverines**, a recent radiotelemetry study in Idaho raised the possibility that human disturbance at natal den sites may cause den abandonment (94593). In 3 instances when researchers disturbed wolverines at maternal den sites, the female and her kits abandoned the area. Four instances of den abandonment due to human disturbance were also recorded in Fennoscandia (951484).

Habitat avoidance has been documented to varying degrees for medium sized carnivores. Banci (410) conducted a thorough review of the **wolverine** literature in 1994. The majority of references to wolverine in the literature are either anecdotal or refer to incidental observations; published research dealing specifically with habitat avoidance and linear developments is almost nonexistent. The following comments regarding habitat avoidance were extracted from Banci's work (410) unless otherwise noted.

The impacts of land-use activities on wolverines are *likely* similar to those on grizzly bears. Wolverines seem to have been most affected by activities that fragment and supplant habitat, such as human settlement, extensive logging, oil and gas development, mining, recreational developments, and the accompanying access. Wolverine populations that are now at the edge of extirpation have been relegated to the last available habitat that has not been developed, extensively modified, or accessed by humans. Conversely, in the north where they are more common, some wolverines tolerate civilization to the extent of scavenging at dumps and living adjacent to urban areas.

No differences in movements, habitat use, or behaviour were noted between logged and unlogged portions of a study area in Montana (6640). Wolverines occasionally crossed clearcuts but they did so in straight lines usually at a running gait, as opposed to their more usual meandering pace (6640).

Females used secluded high-elevation cirque basins for natal den sites (94593). Denning habitat may be a limited and critical component of wolverine habitat when it is viewed in conjunction with potential displacement and disturbance of denning females by winter recreational activities of humans (see individual disruption, above). Snowmobiling in these areas may be a particularly detrimental activity.

Preliminary results from intensive snow tracking in Yoho National Park suggested that wolverines exhibited some general avoidance of the TransCanada Highway (230). On 3 occasions wolverines approached the highway to the edge of cover before veering away without crossing. In another 3 instances, wolverines crossed the highway, but only after they walked or loped in 1 or more small loops (2-20 m) at the edge of forest cover. The 3 successful crossing locations were located where the distance between cover when traveling across the highway was relatively short. The opposite appeared to be the case for close approaches in which the wolverine did not cross. In the same snow tracking study, wolverine use of ski trails was extensive (230). However, it appeared that wide ski trails were used less than narrow ones (230). Copeland (94593) characterized his study area in central Idaho as primarily roadless. However, it was bisected north-south by Highway 121, and bordered on the southeast side by Highway 75. Adult male wolverine home ranges spanned Highway 121 and Highway 75 (94593). Adult female home ranges did not, although they often appeared to border Highway 121 suggesting avoidance of the disturbance corridor. Male wolverines crossed Highway 121 during dispersal movements (94593). In Montana, the size and shape of wolverine home ranges were not affected by rivers, reservoirs, highways, or major mountain ranges (6640).

A winter snow tracking study in Banff National Park supports the premise that wolverines generally avoid human developments (60). No wolverine tracks were seen in the 3 remnant wildlife corridors in the vicinity of Banff townsite. On the Castle Junction transects, 1 wolverine track was encountered well above the Bow Valley floor away from the human developments present there. At Lake Louise, wolverine activity was noted on each side of the TransCanada Highway, but wolverines were not documented crossing the highway. However, in 1 case a wolverine passed through the village of Lake Louise and dug up an ungulate carcass 500 m from the village. Backtracking of a wolverine in the vicinity of the ski hill demonstrated a reluctance to cross roads. The wolverine made several unsuccessful attempts to cross the ski hill access road from east to west in the morning when ski area traffic was generally heavier. It crossed the road only after remaining in the area east of the road for several days.

Buskirk (411) recently reviewed the **marten** literature from the perspective of human impacts. Marten generally avoided habitats that lacked overhead cover. Summer use of nonforested habitats above treeline is common in mountainous areas (411). Biologists generally agree that below the lower elevational limit of trees, 5 km or more of treeless land acts as a complete barrier to dispersal (411). In a study in Colorado, marten avoided traveling >23 m from forest edges (951504). The size of openings that marten have been observed to cross has varied from 10 m to 100 m (e.g., 6431, 5461). In Norway, researchers radiotracking marten in mature and younger age class (presumably logged) coniferous forest suggested that young forests may act as remnant corridors between the preferred stages of mature forest (17010).

Two studies specific to marten and linear corridors were located. In northern Alberta, the movements of wildlife relative to a pipeline corridor were determined through snow tracking (94583, 94573). Marten track data demonstrated no consistent positive or negative responses to habitats adjacent to pipeline-related clearings, although the actual cleared areas were generally avoided. Observations of marten tracks approaching the right-of-way demonstrated a relatively low crossing success rate (50%). However, based on the 2 years of track data from this study, there was no evidence that these impacts resulted in reduced marten activity in the immediate vicinity of the right-of-way. In the northern Rocky Mountains of British Columbia, snow tracking was also used to assess the effects of a newly-cut heli-seismic line (1-2 m wide) on local wildlife (950737). Track data on marten indicated that this species continued to use their ranges, which bordered or crossed the newly-cut line.

Data concerning avoidance effects of disturbance corridors like roads on **fisher** are almost nonexistent; much of the information is either anecdotal or pertaining to incidental observations. The best summary of the existing data was compiled by Powell and Zielinski (413) and the following discussion relies heavily on that work. Fisher usually react to humans by avoidance. Even though these mustelids appear curious by nature and in some instances fishers may associate with humans, they seldom linger when they become aware of the immediate presence of a human. In this regard, fisher are generally more common where human densities are low and human disturbance is reduced. In a radiotelemetry study of reintroduced fisher conducted in northeastern Connecticut, individuals strongly avoided residential areas (2390). Even in intact forests, they tend to avoid large openings and other nonforested areas (e.g., 951524). In the Midwest, fisher have avoided open areas 25 m across and more (951544). Large forest openings, open hardwood forests, recent clearcuts, grasslands, and areas above timberline are rarely used in the west (413).

As was the case with mustelids, habitat avoidance relative to human developments is poorly documented for **lynx**. The lynx's range in the mountains of the western U.S.A. has diminished over the last century, *suggesting* that lynx may be negatively impacted by development (412). Lynx may be less tolerant of human activities in the southern part of their range because suitable habitats are more fragmented (412). The home ranges of 3 radiocollared lynx in Riding Mountain National Park were almost entirely within the park boundaries and lynx did not exist outside the park, suggesting avoidance of the developed area around the park by lynx (951554).

Lynx are known to move long distances but open areas, whether human-made or natural, will discourage use by lynx and disrupt their movements (412). Although lynx will cross openings £100 m in width, they do not hunt in these areas (e.g., 951564). In an on-going radiotelemetry study of lynx in Banff and Kootenay National Park, radiocollared lynx moving within their home ranges regularly cross Highway 93, a 2-lane paved highway, but never cross the TransCanada Highway (C. Apps, pers. commun.). One male did cross the TransCanada Highway during breeding season. Highway crossings occurred at night in areas where there was closed-canopy habitat on either side of the road. Snow tracking over a 5-year period at Sheep River suggested that road segments that were wider and more open on either side were crossed less frequently by lynx and bobcats than narrower segments with cover on either side (951144). Roads in the Sheep River area were closed to public travel during the winter months. In Germany, several highways cut through the Black Forest, but according to a habitat suitability study published in 1990 (5050), there was not enough traffic during the night to present a serious barrier to movements of European lynx.

Snow tracking in the Bow River valley in Banff National Park has shown that suitable habitat in the immediate vicinity of the town of Banff received very little use by lynx (60, 951044). During 2 years of study, just 1 lynx track was recorded in the area around Banff, and it was found in the remnant corridor with the lowest level of human activity. Lynx activity was recorded on both sides of the TransCanada Highway in the Lake Louise area but none were recorded crossing the highway (60). However, lynx crossed the ski hill road and the road to the Fish Creek parking lot north of the TransCanada Highway at Lake Louise. Tracking data demonstrated that lynx used the Whitehorn side of the Lake Louise ski hill between dawn and dusk, even though the area was used by many skiers during the day (60).

Two radiotelemetry studies of **bobcat**, one in Florida and the other in Wisconsin have shed some light on the effects of disturbance corridors on habitat use by this felid. In Florida, 10 female and 16 male bobcats were fitted with radiocollars and were located at regular intervals (70). Telemetry data revealed a total of 72 crossings of highways and main roads by 10 of the collared bobcats. Females rarely crossed roads, whereas males (particularly subadults) crossed roads frequently. Bobcats usually crossed between dusk and dawn.

In northwestern Wisconsin, data from 19 radiocollared individuals suggested that bobcats selected home ranges with relatively higher densities of trails and lower densities of secondary highways (660). The density of all road types in bobcat home ranges was 1.5 km/km^2 and the least-used disturbance corridor type, trails, contributed 32-70% of all disturbance corridor classes within home ranges. Male and female home ranges contained similar road densities for all road types. Within established home ranges, bobcats crossed secondary highways, unpaved roads, and trails in proportion to their occurrence and crossed paved roads less than expected. Geographic selection or avoidance of particular road types appeared to be related to vehicle traffic levels and habitat composition levels within a 100 m-buffer zone on either side of a disturbance corridor. Roads with higher traffic levels also tended to have relatively poorer bobcat habitat on either side and were avoided, while roads with less traffic were located within better bobcat habitat and were not avoided. High variability in traffic levels on unpaved roads made any correlations between traffic levels and crossing frequencies difficult to discern.

In northeastern Alberta, the nature and extent of **river otter** encounters with various disturbance corridors (seismic lines, pipelines, high-grade roads) were investigated (950767). Reactions to these disturbance corridors were recorded during continuous snowtracking of otters between points of water access (259 km and 94 encounters), and during isolated investigations of tracks in snow and sand at intersections with gas field corridors (32 encounters). Relationships between home ranges of radioinstrumented otters and disturbance corridors (13 marked otters, 193 encounters) were also examined. Only 12 of 94 encounters from the continuous snow-tracking sample resulted in behavioural disturbance (a definite change in direction to avoid the corridor). These few disturbed reactions were mostly associated with major disturbance corridors which were under construction at the time, and the unfamiliar noise and visual disruption of vegetation were thought to be the disturbing stimuli. High levels of human use were not significantly associated with disturbed reactions, indicating that otters became accustomed to the stimuli presented by well-used disturbance corridors. Otters used culverts to travel under roads if the stream gradient and current were not altered. The data from isolated sampling and from radiomarked otters strengthened the conclusion that otters were accustomed to all disturbance corridors associated with the oil and gas field where public access was limited.

As was the case with their larger cousins, linear developments may result in **habitat enhancement** for certain medium-sized carnivores. For example, during winter and summer, lynx often traveled along road rights-of-way <15 m wide, where adequate cover was present on both sides of the road (412). Forbs, grasses, and shrubs that grow along the edges of roads can benefit hares and attract lynx (412). Similarly, where snow was deep, fisher foraged for hares on packed, snowplow drifts along roads that bisected hare habitat (951534). In southeastern British Columbia, badgers also used disturbance corridors like roads as travel routes and banks along the roads may be considered attractants since these slopes were often easy to burrow in (N. Newhouse, pers. commun.). However, the advantages gained by using this habitat may not benefit the carnivore population, since the risks of human-caused mortality are also greater along disturbance corridors (see below).

Direct mortality has been documented among many medium-sized carnivore species as a result of linear developments. Most direct mortality was associated with vehicle collisions. Records of marten (410, 3850), long-tailed weasels (14960), mink (3850), lynx (2130, 3850, 951574), river otters (4870, 5700), badgers (3850, 14290, 15220, 950797), foxes (950797), coyotes (3850, 950797), wolverine (640), bobcat (950093), and lynx (951574) were all found in the published literature.

The importance of this mortality to the viability of local carnivore populations has not been as well-documented. In Spain, human activities were the main cause of lynx mortality in a protected area and road traffic accounted for 16.7% of all human-caused mortality (2130). In New York State, 6 of 50 translocated lynx were killed on roads (951574). River otters appear prone to vehicle mishaps. In Idaho, 2 of 7 instrumented otters were killed on roads, while another unmarked otter was also a road mortality (4870). Coyotes are also frequently killed. In 1994, coyotes represented 2.5% (133 coyotes) of all kills found along British Columbia's highways (950797). In the Florida bobcat study cited above (70), 3 of 26 collared bobcats were hit by cars. During a companion study of road mortality along portions of SR-84/I-75, 13 bobcats were found (950093). Over the last 3 years, at least 4 wolverines were killed on a 198 km stretch of the Canadian Pacific Railway between Revelstoke and Field, British Columbia (951644). The effects these mortalities may have had on the viability of local or regional populations was not determined.

Indirect mortality as a result of roads and other linear developments are also frequently documented in the literature of these medium-sized carnivores. Most indirect mortality occurred as a result of human access along roads and other linear developments. Most of these species are hunted and/or trapped, and access typically results in increased mortality for them (e.g., lynx [410, 3600], bobcats [70, 520, 950964], river otters [4870], marten [15040]). In boreal forest habitat in Ontario, resident marten in uncut forests had higher mean ages, were more productive, and suffered lower trapping mortality than those in logged forests (17390). Logged forests had an associated road network allowing easy access into the areas. Even in areas that were under complete protection, new roads provide access for illegal activities. In Spain, illegal trapping accounted for 41.7% of all lynx deaths (2130).

The primary mortality factor for wolverines is trapping and hunting (410). In a Montana study, trapping caused 83% (15 of 18) of recorded mortalities (6640). The incidence of known mortality for radio collared wolverines in all field studies has been 30% (24 of 80) and trapping and hunting accounted for 58% of all known mortalities (18790). Given the low reproductive potential of wolverines (18790), the cumulative effects of forest access, trapping, and hunting on wolverines may be detrimental to regional populations, although current information is insufficient to predict when the impacts of particular land-use activity might be excessive (410).

7.6 Elk

The most direct disturbance elk suffer as a result of linear developments is the **disruption of individuals**. Humans use linear developments such as roads and cutlines, and elk move away from these human disturbances. The degree to which elk populations react to humans varies considerably depending on their previous experiences. The immediate response of elk to disturbance associated with timber harvest in an area open to elk hunting was investigated in 5 studies in Montana (7570). In several studies elk responded by moving away from the disturbance (2610, 7450, 6520). Measured displacements ranged up to 8 km with the greatest movements detected when heavy equipment on a ridge line was visible over a large area (9560). Most often the distances moved were the minimum necessary to break visual contact with men and equipment (e.g., 951724). Displacement of elk during road construction and logging was temporary; elk tended to move into areas of logging activity on weekends during non-active periods. These movements were probably a response to the availability of some desirable habitat feature rather than habituation to the disturbance (14450). In the Bridger-Teton National Forest, elk were frequently displaced by recreational users, particularly crosscountry skiers (950717). On winter range in the Highwood River valley in southwestern Alberta, most road crossings and feeding on the right-of-way by elk were at night. (6620). There are hidden costs to temporary displacement. Displacement means there is a reduction in usable habitat and an increase in stress during the period of displacement (94273). Relative to disturbed elk, undisturbed elk spent very little time engaged in activities involving high heart rates (7450).

The disruption of individuals also can occur in protected elk populations. Again in these populations the disruption seems to be dependent on the degree to which individual elk are exposed to humans. In Yellowstone National Park, the response of elk to human disturbance on winter range was markedly different in areas of continuous human activity (Mammoth) compared with more remote areas of the park (Lamar Valley and Stephen's Creek)(15360). The median distance at which elk began to move away from people (non-motorized) at Lamar/Stephen's Creek was 400 m, whereas the median flight distance at Mammoth was 15 m. Median distances that elk moved away from disturbance were 42 times greater in Lamar/Stephen's Creek than at Mammoth. No evidence of elk habituation or avoidance was associated with repeated disturbances during the study. After being disturbed, elk in the Lamar and Stephen's Creek moved uphill, to steeper slopes, and closer to trees. In 78% of disturbances at Lamar and Stephen's Creek (n=40), the elk left the drainage. Distance moved was correlated to the distance to the nearest ridge; elk tended to move over the nearest ridge to be out of sight of the human disturbance (15360). In Rocky Mountain National Park in Colorado, elk which experienced little or no hunting, were very visible and were disturbed little, if any, by normal on-road visitor activities (12310). However, people approaching animals away from roads usually caused elk to leave open areas. During winter and spring, elk in the park could be approached significantly closer during darkness with artificial lights than during daylight.

Different sex and age classes of elk may also be affected by disturbances in different ways. In southeast Idaho, disturbed calves moved greater distances, used larger areas, showed greater use of coniferous forest, and lacked selection for favorable physiographic parameters when compared to undisturbed calves (14350). Cow/calf pairs readily abandoned their traditional calf-rearing area under human and simulated mining disturbance, although no calf abandonment was documented.

Habitat avoidance is the most serious effect linear developments may have on elk. Human entry into an area occupied by elk for any purpose may reduce the security of the habitat in that area for elk. Again, the degree of habitat avoidance is directly related to the types and amounts of human disturbance to which elk are subjected.

In protected areas avoidance of habitat in the vicinity of roads and other linear developments is either nonexistent or very short-term. In Rocky Mountain National Park during autumn, numbers of elk seen, rates of bugling, times of arrival and departure of elk to and from meadows, and harem bulls' activities were analyzed for relationships with traffic volume and tourist activities (12310). Results suggested small effects of traffic volume upon elk, but no trends were statistically significant. Elk made greater use of areas near roads as the winter-spring study progressed. Habitat availability away from the road may have declined as the winter progressed because of increased snow depths and depletion of food resources. In Yellowstone National Park, displacement of elk by skiers in remote areas was usually temporary and longer term avoidance was not demonstrated (15360). However this tendency to return after disturbance may decline with repeated disturbances (1435). In the backcountry of Yellowstone, in 5 of 40 disturbances elk did not return to drainages they left when disturbed (15360). However, this could not be attributed solely to disturbance since elk sometimes left drainages without any human disturbance.

Declines in use of habitat adjacent to forest roads have been documented in studies of hunted elk in most of their range in North America (7580). Avoidance distances are quite variable and dependent on the amount of traffic on the roads, the type of traffic, the topography of the area, and the ratio of closed and open habitats. The loss in habitat effectiveness has been shown to be greatest near primary (paved) roads, and least near primitive roads, greatest where cover was poor and least where cover was greatest, and greater during the hunting season than at any other time of the year (7570). Road avoidance could be affected by habitat availability. In Colorado, winter habitat was more available to cervids west of the continental divide than to the east because of higher snow accumulations east of the divide (13630). More pronounced avoidance of roads west of the divide presumably resulted from a greater availability of habitat away from roads (13630). Avoidance distances of 200 m to >1,600 m have been documented in Montana, Oregon, Washington, Idaho, and Colorado (e.g., 11870, 14450, 13630, 4320, 4620). In north-central Idaho, elk in roaded areas used habitats with greater canopy cover (2070). This was most pronounced for cow and 2+ year-old bull elk. Yearling bulls tended to select habitats in proportion to availability, whereas cow and 2+ year-old bull elk showed preference for open timber habitats during fall in unroaded habitats and for timber habitat in roaded areas during summer and fall. Bulls tended to use higher proportions of lower slopes and stream bottoms than cows during summer, and somewhat steeper areas during fall. Summer home range size was positively correlated to the proportion of open timber and to road density within home ranges (2070).

Morgantini (860) radiotracked 70 elk in a hunted population in southwestern Alberta to determine whether access features had an effect on elk distribution. His preliminary results based on 4,409 radiolocations and visual sightings were similar to those determined in Montana and are outlined below. Within the Pincher Creek study area elk appeared to avoid habitat within 300 m of primary (paved) roads in all seasons. Secondary roads (gravel) did not appear to exert as strong an influence on habitat use, but elk avoided secondary roads in autumn and winter. Elk appeared to avoid habitat within 100 m and 200 m of pipelines and transmission lines, respectively, in spring, autumn and winter, and avoided habitat within 300 m of these features in autumn. Elk did not appear to avoid seismic lines and cutlines. Seismic lines and cutlines tend to be narrower in width than pipelines and powerline corridors. In fact, the data showed a higher than expected number of elk within 100 m, 200 m, and 300 m of seismic lines and cutlines in all seasons but winter.

In the Castle-Carbondale study area there were more elk than expected in all seasons within undisturbed habitat (at least 500 m from any form of access). Fewer than expected elk occurred within 300 m of primary roads in all seasons except spring. Fewer than expected elk occurred within 250 m of secondary roads in all seasons except spring. Secondary roads had less influence on habitat use than primary roads at distances of >250 m. There was no significant difference between the observed and expected number of elk observations within 500 m of seismic lines and track trails. Elk were found closer to these access features in the spring than in summer, fall, and winter. Observations during summer, autumn, and winter within 250 m of these access features were lower than expected. Data from this study seemed to indicate that truck trails and seismic lines had less influence on elk habitat use than did primary and secondary roads. From a habitat use perspective, Morgantini found that during the autumn (hunting season), conifer stands were highly selected for, while grasslands were utilized much less than expected and cultivated areas were completely unused (860).

Similarly, in westcentral Alberta, hunted elk tended to avoid areas surrounding a pipeline corridor during winter construction activities; higher numbers of elk were seen farther from the pipeline right-of-way during construction periods as compared to periods with no construction activity on the right-of-way (3110).

The actual amount of habitat lost because of reduced use by elk can be calculated from the avoidance data cited above (7580). Summer data from Washington showed that elk use was 35.2% of potential in plots 30 m from the road (10610). Using the Washington data, Lyon (7580) calculated that the average use of this 60-m corridor was 17.6% of potential. Therefore, the 6.1 ha on either side of 1.0 km of road receive only as much elk use as 1.1 ha of undisturbed elk habitat of the same quality. Between 30 m and 200 m, average use was 46.7% of potential. Along 1 km of road, the 34 ha of elk habitat between 30 and 200 m distant from the road was the equivalent of 16 ha of undisturbed elk habitat. Lyon continued these calculations out to 1.6 km from the road and determined that habitat effectiveness was reduced by 57 ha/km of road. Using data from Montana (9550, 9560) and Idaho (Scott and Peek 1980 cited in 7580), Lyon calculated that habitat effectiveness was reduced by 76 ha/km and 91 ha/km, respectively.

Several attempts have been made to model the effects of road density on habitat effectiveness for elk (e.g., 9550, 11590). By reanalyzing 3 data sets that documented avoidance of a secondary (unpaved) road corridor in summer, Lyon (7580) concluded that in the average situation, habitat effectiveness can be expected to decline by at least 25% with a road density of 1 mi/mi^2 (0.62 km/km^2) and by at least 50% at 2 mi/mi^2 (1.24 km/km^2).

Problems with determining the extent of the loss of habitat effectiveness for road densities exist because few of the available data were collected where elk were using areas with road densities >2 mi/mi^2 (1.24 km/km^2)(7580). However, in the Montana elk-logging-road study between 1970 and 1985, in 20 observations of road density of between 2-3 mi/mi^2 (1.24 - 1.86 km/km^2), elk use averaged 47.5% of potential. As road densities increased to 5 - 6 mi/mi^2 (3.1 - 3.72 km/km^2), elk use declined to less than 25% of potential. In the 7 areas with an average density of 5½ mi/mi^2 (3.41 km/km^2), elk use was 18.8% of potential (7580). These averages are somewhat misleading because most of the samples with road densities >3 mi/mi^2 (1.86 km/km^2) involved newly-constructed roads in a timber sale area. In the year following construction, elk use was 56.9% of potential. By the third year, logging was nearly completed and elk use had declined to 25%. Despite a closure to all but essential traffic, elk use declined to 20.4% of potential in the fifth year after road construction. The full impact of a road did not occur until at least the third year after construction. Thus Lyon (7580) assumed that the best estimate of habitat potential for elk as influenced by traveled roads is represented by elk use in habitat with roads more than 2 years old.

The responses of 2 hunted elk populations to disturbances associated with ski area expansion showed that elk may avoid areas where only physical disturbances occur (18680). Development at the Vail ski area consisted of physical disturbances only (disturbed ground was 3-5% of the study area), while development at the Beaver Creek ski area was primarily comprised of increases in human activity. Elk use at Vail after development decreased to 30% of pre-development elk use. This decrease was primarily influenced by a decrease in elk use of the most-developed bowl, where elk use in the first post-development year was 4% of pre-development levels. At Beaver Creek where human activity increased, the number of elk observed decreased dramatically; elk use in the first post-development year was 2% of pre-development use. After development, elk use at the Beaver Creek study site was lowest when human activity was highest. Post-development elk use at both study sites indicated that elk partially acclimated behaviourally because the number of elk seen increased linearly each year after development. However, since these relationships could level off in later years, complete recovery should not be assumed.

Habitat avoidance can also occur if some or all individuals in an elk population are unwilling to cross disturbance corridors, that is, the corridors act as barriers or filters to movement. Winter construction of a 109 cm diameter pipeline was routed though elk winter range in westcentral Alberta (3110). Monitoring of the pipeline right-of-way during construction showed that only 52% of 23 groups of elk that encountered the pipeline lying on the right-of-way or elevated on blocks successfully crossed it (3110). Earth and snow berms were associated with another pipeline construction project through elk winter range in westcentral Alberta (3140). Impacts of berms were reduced by the presence of breaks and openings. In this case, 2 and 3 pipes were laid. However, because of their small diameter (9, 11, 46, 6, 17 cm), unwelded and welded pipe strings individually did not present a barrier to ungulates. Overall, failure to cross berms was 9% of the total number of elk encounters. However, 2 or more welded pipe strings were a major filter to movement across the right-of-way. The filter effect resulted from the presence of 2 or more pipe strings, their height and distance apart, and the presence of dirt berms and sometimes ditches. Elk failed to cross 33% (5 of 15) of the time when 2 welded and 1 strung pipe (47 cm) are encountered (3140). In Yellowstone National Park, elk did not cross a buck-and-pole fence (165-185 cm high, 165-175 cm basal width) that was built on part of the northern border of the park. Closure of all gates in the fence stopped virtually all crossings by elk and bison (7890).

Disturbance corridors such as roads can also cause **social disruption** of elk populations. In Washington, maximum herd size in an elk population living along a recently opened Forest Service road decreased in 1987 in a response to frequent passive harassment by humans, such as getting out of cars (4620). Increased road access into an area open to hunting without adequate regulations can lead to excessive bull mortality (15630), altering the social structure of the local elk population.

Habitat disruption for elk occurs when habitat is lost to linear developments. Roads affect elk directly by removing habitat. A single-lane road 6.7 m wide removes 0.68 ha/km of elk habitat (10570). Linear corridors can result in considerable habitat disruption if a high density of roads exist in an area. However, this loss of habitat is minor when compared to the loss of habitat on either side of the road resulting from habitat avoidance.

Linear developments can have a positive effect on elk through **habitat enhancement**. For example, summer forage biomass in a transmission-line corridor in northern Japan was 5 times greater than in the adjacent forest (10130). The disturbance corridor was more beneficial than a large clear-cut area because it provided more forest edge per area. Wet meadows, dry meadows, clearcuts, and revegetated roads were preferred as grazing sites, while mature and stagnated forests were clearly not preferred in a study of the diets of tame elk in a lodgepole pine forest in the northwestern U.S. (12920). Wet meadows, revegetated roads, and mature forest were preferred for resting and nongrazing activities. Elk were also attracted to highway rights-of-way to forage in Jasper National Park (7010). In southwestern Alberta, Morgantini (860) found that although fewer than expected elk occurred within 300 m of primary roads in summer, fall, and winter, this was not the case in spring, probably because roadsides tended to green up sooner in the spring than surrounding habitat (860). Brusnyk and Westworth (2920) reported similar effects for pipeline rights-of-way in westcentral Alberta. Construction of the pipeline right-of-way increased wildlife habitat diversity. Elk seemed to respond primarily to greater forage supplies along the pipeline (2920).

Linear developments can result in **direct mortality** for elk. Direct mortality is generally associated with primary roads where elk are hit by vehicles. Elk are killed on highways wherever elk range is bisected by roads (e.g., 7240, 9960). Many large mammals are killed annually on the TransCanada Highway in Banff National Park and this mortality involves variable numbers of all species including elk (e.g., 4110, 6580, 3760, 3870, 3880). Over the ten-year period 1978 to 1987, a total of 471 large mammals was known to have been killed by vehicles on the Kootenay Parkway; 46.5% were elk. The mean annual kill rate of ungulates over the ten-year period was 0.5 animal/km/yr; the highest kill rate was for elk (0.5/km/yr) (580). Big trucks were implicated in a disproportionately large share of the mortalities (590). The width of a highway appears to affect the numbers of animals killed. When a section of the TransCanada Highway was twinned in advance of fencing, elk road kills increased significantly (1206). Traffic volume may also contribute to higher kill rates. Along the untwinned portion of the TransCanada Highway between Banff and Lake Louise, as traffic volume and elk numbers have increased, the number of elk kills on the highway have increased as well (690). Along the Kootenay Parkway, the greatest collision frequencies corresponded to the locations and periods (seasonal and diurnal) of heaviest ungulate use of the Parkway corridor and right-of-way, and not necessarily to periods of greatest traffic volume. Traffic volume was a factor, however, when high volumes corresponded to the critical periods of ungulate use (580).

Indirect mortality occurs as a result of linear developments because these corridors allow human access into areas for hunting and poaching (e.g., 11570, 94303). In north-central Idaho, 121 elk were radiomonitored in forested habitats from 1986-91 to determine cause-specific mortality and habitat use patterns (2070, 15630). Sixty-nine deaths recorded during this period included 60 human-caused mortalities directly associated with hunting. Three elk were poached. The probability of mortality increased with increasing road and hunter densities, and was lower in areas with highly broken or dissected terrain. In Montana, analysis of data from 2 hunting districts revealed large increases in vulnerability in the mid-1960's concurrent with periods of peak road construction and logging. However resolution of the data were insufficient to detect incremental increases in vulnerability during the most recent decade (2340). In 1 hunting district where elk migrated from large tracts of secure habitat to concentrate in highly fragmented, accessible places, weather accounted for up to 50% of the variation in the harvest. If inclement weather during the hunting season caused elk to migrate to these accessible winter ranges, harvests increased. In the second hunting district where elk migration was less pronounced and elk were uniformly more accessible, numbers of hunters and road density were more important in determining vulnerability (2340).

Population effects as a result of linear developments have been documented in the mountain parks of western Canada. In 1979, Holroyd predicted that if the trends of elk mortality on the highways continued, elk numbers in Bow Valley would be severely reduced (6580). A similar situation existed in Kootenay National Park where a year-long investigation into ungulate mortality along the Kootenay Parkway concluded that wildlife-vehicle collisions were a serious concern, particularly to park elk populations (590). Current levels of mortality on the Kootenay Parkway were considered contributory, along with habitat loss and natural mortality, to the observed decline in the park elk population (580). As Shank (9230) pointed out, significant behavioural effects do not necessarily result in population effects. This is particularly true in the short term. In a study of mining disturbance and calf elk, significant behavioral effects were documented but winter survival did not appear to be effected (14350).

7.7 Caribou

The effects of linear developments on barren-ground caribou have been studied extensively in northern Canada and Alaska. Development impacts have not been examined to the same degree in woodland and mountain caribou populations.

Individual disruption of caribou may occur along linear developments such as roads. The physical presence of roads does not appear to be a problem (e.g., Dempster Highway [7950]), but the traffic and in particular, people outside of cars, may cause disturbance to individuals. Behavioural responses of barren-ground caribou to a pick up truck on the Dempster Highway were documented by Horejsi (6600). Forty-eight percent of animals reacted to the vehicle by running away, while another 38% trotted away. Duration of flight was almost twice as long for females as for males. The road itself was treated as a novel object. Flight distance did not vary between open and treed habitats or between sexes. Mean flight distance for males was 167 m and for females 144 m. The data suggest that fast-moving vehicles were particularly frightening to caribou (6600). Research conducted during 1973-74 in Mount McKinley National Park showed that traffic associated with the park road disrupted feeding times and spatial distributions of caribou (1220). Evidence from a follow-up study 10 years later showed that caribou appeared to be habituating to the road (9320). However, individual disruption still occurred. More caribou responses occurred during summer when visitors were out of their vehicles than when vehicles alone were present (9320), and most of the increased wildlife responses after lifting of travel restrictions in the fall were due to visitors leaving their vehicles. In studies in the Prudhoe Bay oil field, many localized responses of caribou to roads, pipelines, vehicle traffic, and other structures and activities were observed (5490), although caribou on experimental and control sites had similar movement rates and activity budgets. In southern British Columbia, woodland caribou in the Selkirk Mountains continued to use a traditional movement route across Highway 3 and after its construction they appeared to be habituated to the road (8610).

The reactions of mountain caribou to snowmobiles in British Columbia were studied for 1 winter west of Revelstoke, British Columbia (11340). Groups of caribou were approached 18 times using either 1 or 2 snowmobiles. No group was approached closer than 100 m. Seven groups ran away, 8 walked away, and 3 showed no reaction. Flight distances were shortest when caribou saw the approaching snowmobile (mean=139 m). Scent and sounds elicited successively greater flight distances. Sound alone was associated with the greatest flight distances (mean=286 m). Caribou usually moved less than 1 km away immediately after the disturbance (mean =0.6 km, n=15) and in all but 1 case, continued to use the area within 2 km of the disturbance site. The experimental disturbance by 1 or 2 snowmobiles never caused caribou to cross a valley or move to another ridge. The data indicated that the aspects of snowmobiling most disturbing to caribou were human scent and large groups of machines moving rapidly around an area. Based on this work, Simpson (11340) felt that caribou were able to tolerate low levels of snowmobile use and, if they were not harassed by snowmobiles, their tolerance would likely increase.

Avoidance of habitat by barren-ground caribou in the vicinity of disturbance corridors has been investigated for over 20 years on Alaska's North Slope. Female caribou with calves avoid the TransAlaska Pipeline (3930). In the summer there was a lower percentage of cow:calf groups along the disturbance corridor than away from it. A follow-up study 5 years later demonstrated that local abnormalities in caribou distribution and group composition, resulting primarily from avoidance of the disturbance corridor by cows and calves, continued to be apparent (3960).

At Prudhoe Bay, a similar picture emerged. Caribou were surveyed repeatedly from the road network of the oilfield complex between mid-June and mid-August 1978 (9410). Researchers recorded 1,694 caribou within or adjacent to this complex, with an overall average of 10% calves. By comparison, corresponding aerial surveys within the general region yielded a minimum estimate of 23% calves. In a second study, aerial surveys were conducted annually in June 1978-87 to determine changes in the distribution of calving caribou that accompanied petroleum-related development (15810). With construction of an oil field access road through a calving concentration area, mean caribou density (no./km^2) decreased from 1.41 to 0.31 within 1 km and increased from 1.41 to 4.53 at 5-6 km from the road. Concurrently, relative caribou use of the adjacent area declined, apparently in response to increasing surface development. This perturbed distribution associated with roads reduced the capacity of the nearby area to sustain parturient females and insufficient spacing of roads may have depressed overall calving activity (15810). A third study used radiotelemetry to examine the distribution and movements of 141 radiocollared female caribou during summer, 1980-1993 (14620). Both abundance and movements of radiocollared females in the area encompassing the intensively-developed Prudhoe Bay oilfield complex were significantly lower than in other areas. The authors stated that the avoidance of, and fewer movements within, the complex by female caribou were apparently in response to the dense network of production and support facilities, roads, above-ground pipelines, and the associated vehicular and human activity (14620).

The results of avoidance of oil and gas developments in the Prudhoe Bay area by caribou were examined in more detail by analyzing post-calving habitat (950727). Under disturbance-free conditions, caribou preferred rugged terrain immediately post-calving and avoided areas with flatter terrain. Displacement of maternal females from a zone within 4-km from a road and production-related facilities reduced usage of rugged terrain types in that zone by 52%. This reduction was accompanied by a 43% increase in caribou use of rugged terrain 4 to 10 km from surface development.

Avoidance of development corridors by migrating caribou has not been unequivocally documented. Bergerud et al. (610), in their summary of various caribou herds across

North America, believe that all documented changes in migration patterns could be attributed to changes in population size and concurrent shrinkage in range sizes. They cited numerous cases where migrating caribou cross highways in Alaska and elsewhere in spite of intensive hunting pressure along these development corridors.

Avoidance of disturbance corridors by woodland and mountain caribou has not been as well documented to date. Preliminary results from a major study of caribou, wolves, and moose in northeastern Alberta show that caribou locations (n=4255, 121 individuals) were further from linear corridors than random in winter, closer or no different from random in spring, and no different from random in summer (950587). In a study of the impact of seismic operations on large mammal behaviour in the Copton Creek - Kakwa River area of Alberta, Horesji found that caribou avoided areas of human activity (19210). Radiotelemetry data from woodland caribou in northwestern Alberta did not establish a link between industrial activity and caribou behavior (350). The authors acknowledged that some range shifts by radiocollared caribou could be interpreted as avoidance behaviour. However, the intensity of radiotracking (605 radiolocations over 36 months) was probably not sufficient to determine whether caribou avoided oil and gas developments in the area.

In the study of the effects of snowmobiles on mountain caribou in British Columbia (11340), snowmobile use changed caribou distribution on Frisby Ridge. From 1981 to 1983, most caribou were found at the south end of Frisby Ridge in February and gradually moved north. By April, no animals remained on the south part (most accessible and most used by snowmobiles) and over 50% were on the northernmost part of the ridge. Following closure of the middle portion of the ridge in 1984-85, most caribou remained on that part of the ridge throughout the season. It was used significantly more by caribou after snowmobiles were prohibited than before. Fewer animals used the southern portion (the portion of the ridge that remained open to snowmobiling) and their numbers again decreased to zero by April. Movement of caribou from south to north on Frisby Ridge coincided with increasing snowmobile use, largely at the south end of the ridge, from January through April. Intensive use, averaging 22 snowmobile hours/day at its peak, caused caribou to move away from the south end of the ridge.

Properly-constructed pipelines do not appear to be major barriers to movement. The presence of the TransAlaska Pipeline did not appear to affect the traditional migration of the Nelchina caribou herd (13670). In 1981 through 1983, an estimated 7,909 caribou were recorded on the pipeline right-of-way, of which all but 4 crossed. The disturbance corridor averaged 30 m wide and consisted of a pipeline, a driveable gravel pad, and adjacent cleared area. The 122-cm pipeline was elevated for 61% of its length, the average height was 2.4 m, and 93% of heights were over 1.8 m. Caribou used the traditional migration routes as described prior to construction of the pipeline. The locations of pipeline crossing points were associated with topography and terrain features rather than characteristics of the pipeline. Refrigerated burial sections of the pipeline placed at traditional migration routes were heavily used. However, caribou continued to cross the pipeline along traditional migration routes where special crossing structures were absent (13670).

If roads and pipelines are immediately adjacent to each other, caribou may have more difficulty crossing the disturbance corridor. In these cases, the disturbance corridor was acting as a filter to caribou movement. In the Prudhoe Bay and Kuparuk oil fields on the Arctic Coastal Plain, caribou crossed an elevated pipeline or a road with a frequency similar to a control (4580). It was only where a pipeline paralleled a road with traffic, that crossing frequencies were significantly less than expected (30% versus 66%). Caribou crossing under elevated pipelines did not select for particular pipe heights within the range studied (152-432 cm). Smith and Cameron (950447) reported on reactions of 2 large groups of caribou that illustrated the effects that these larger disturbance corridors can have on caribou movements. In the first case, the authors watched a herd of 917 mosquito-harassed caribou over a 12-hour period in the Kaparuk Development Area. About 419 (46%) crossed elevated sections of the Kaparuk Pipeline in 26 separate attempts (without recrossing), 122 (13%) crossed buried sections of the pipeline, and 201 (22%) trotted or ran parallel to the pipeline for at least 32 km without crossing. Overall, less than 60% of the original group was known to have crossed the pipeline. In the second incident, 655 caribou were observed for 8 hours. Thirty-seven group crossing attempts were recorded and during 36 of these attempts, 169 (26%) caribou crossed under the elevated pipe. In the other attempt, an entire group of 249 (37%) crossed at a buried section of pipe. An estimated 247 caribou left the main group and their movements could not be determined. In total, 64% of the original group was observed crossing the disturbance corridor. The majority of crossing attempts occurred near the intersections of lakes with the road/pipeline complex, but crossing success was highest at a section of buried pipe isolated from road traffic.

Limited data from Alberta suggest that buried pipeline right-of-ways do not appear to have any barrier effects on caribou movements. In westcentral Alberta, Morgantini recorded 7 woodland caribou crossing a pipeline right-of-way and it was likely that the same herd crossed the corridor several times over a week-long period in December (3130). Observations of tracks on and in the vicinity of a buried pipeline right-of-way in northern Alberta indicated that the physical presence of the pipeline did not obstruct movement although some caribou were deflected for short distances along the right-of-way (94583).

Caribou may find berms associated with pipelines a visual barrier that results in behavioural disturbance in a manner similar to other ungulates. In northern Alaska, the behaviour of caribou encountering an experimental gas pipeline berm was monitored. Responses of the animals indicated that a visual barrier greater than 1.2 m above ground level had a pronounced effect of deflecting the movements of caribou. Animals readily traversed lower berms but avoided higher berms (10040).

Linear developments like roads, seismic lines, cutlines, and pipelines through caribou habitat cause **habitat disruption** by removing caribou habitat. In 1 area of northwestern Alberta, oil and gas exploration has occurred since the mid 1970's and there are 2.08 km of linear development per km^2 (950787). Those linear developments account for approximately 13,900 ha of caribou habitat or 2% of the study area, if an average right-of-way width of 10 m is used for all of the linear corridors. However, the direct loss of habitat is likely insignificant relative to the other disturbance effects that result in habitat avoidance and mortality.

Linear developments like roads, seismic lines, cutlines, and pipelines through caribou habitat can also result in **habitat enhancement.** Along the TransAlaska Pipeline haul road, caribou were attracted to new shoots of *Equisetum* and *Eriophorum* growing in the dust-covered wet meadows along the road (3860). In the MacKenzie River valley and in northern Alberta, incidental sightings of caribou tracks along a pipeline right-of-way indicated that it was used year-round as a movement corridor for short distances and as a spring and summer forage source (94583, 94573).

Caribou populations suffer **direct mortality** when their ranges are intersected by roads and vehicle collisions occur. Collisions with vehicles do not appear to be an important source of mortality for barren-ground caribou, even in Alaska where a number of highways bisect caribou range. However, road kills are a serious problem in 1 area of Alberta (18840) and may be a problem in others where caribou populations are small and any mortality may have significant effects on individual herds. A small herd of migratory mountain caribou in westcentral Alberta sustained a high level of mortality due to vehicle collisions in the early 1990's. During winter 1991-92 and 1992-93, caribou mortality due to vehicle collisions was extremely high on a 35 km section of Highway 40 between Grande Cache and Hinton in westcentral Alberta (260). At least 32 caribou were hit by vehicles resulting in 27 known deaths and 5 animals that may have died later because of their injuries. The problem of caribou mortality on Highway 40 is likely to recur because the highway bisects the traditional winter range of the A la Peche herd, and the behaviour of the animals has indicated that they were becoming increasingly attracted to road salt. The monitoring program conducted by Alberta Fish and Wildlife Services in winter 1992-93 confirmed that caribou used the right-of-way primarily to obtain salt from the pavement surface. Most collisions occurred between mid-October through November, but caribou were hit in all months from October through May. Most collisions occurred at night (260). The Selkirk mountain caribou herd in southeastern British Columbia has also suffered traffic mortalities; 7 were killed between 1967 and 1975 on Highway 3 between Salmo and Creston (50357). Traffic mortalities continue to occur in the region.

Four of 7 recorded caribou fatalities on British Columbia roads in 1994 were from the Kootenay Region (950797).

Linear developments produce **indirect mortality** primarily by allowing human access into previously remote areas. Disturbance corridors like roads are the most important factor in determining the level of hunting mortality a caribou population sustains (e.g., 610, 950655). Hunting pressure in British Columbia in the early 1900's was concentrated on more-accessible herds so the harvest impacts were much greater in those areas (950639). Although caribou hunting has been either eliminated or severely curtailed in British Columbia and Alberta, legal and illegal hunting continue to affect local caribou populations and the continued development of road systems has provided ready access for hunters. In an on-going study in northeastern Alberta, 5 caribou mortalities attributed to humans were significantly closer to linear corridors than would have been expected by chance (950587). Illegal hunting accounted for 75% of recorded deaths within the Selkirk caribou population between 1967 and 1983 (950357).

Humans are not the only hunters that make use of the access provided by development corridors. Wolves have been recognized as important predators of caribou (e.g., 855, 1684, 2960, 950487). Bloomfield and Edmonds (950242) noted that extensive snowmobile trails through caribou winter range provided a means of easy travel for wolves. Once wolves discover packed access routes into previously inaccessible caribou winter range, wolf predation on those caribou will increase (610). Similarly, forest harvesting practices in British Columbia that produce a patchwork of different forest age classes linked with a network of roads probably will not provide an environment where caribou can effectively avoid wolves (950639). Preliminary results from the on-going study in northeastern Alberta (950587) suggest that development corridors influence the distribution of wolves. Radiolocations of wolves were closer to these corridors than would be expected by chance. Wolves have also been observed to use development corridors. However, caribou killed by wolves were not located closer to corridors than random. This may be because the sample size was small, or caribou were able to mitigate the effects of development corridors by avoiding them (950587).

Human disturbance associated with development corridors may also force caribou into areas that have increased natural hazards. In northern Ontario, caribou winter ranges appear to be in areas where moose and wolf densities are lower. Disturbances within these winter ranges may force the caribou to move into surrounding areas containing higher densities of moose and wolves (950657, 950647). In some areas of British Columbia, caribou are vulnerable to being killed by avalanches during winter. Caribou generally prefer more gentle terrain in winter, but excessive disturbance by snowmobiles can displace caribou into steeper, more avalanche-prone terrain (e.g., 11340, D. Seip pers. commun. in 950641). Therefore, snowmobiles and other disturbances that displace caribou from preferred winter ranges may increase their risk of natural mortality

(950641). On Alaska's North Slope, wolf predation was the major cause of death for radiocollared barren-ground caribou calves after the first 48 hours. Mortality increased toward higher terrain away from the coastal plain, where the majority of calving has traditionally taken place (8610). Additional data from carcasses of unmarked calves corroborated the trends noted for radiocollared cows and calves. The authors concluded that if petroleum development displaced calving from the coastal plain where the majority of oil and gas development has taken place to date, calf mortality would likely increase.

Population effects have been documented in woodland caribou populations. Seip and Cichowski (950639) felt that overhunting was probably responsible for population declines in many areas of British Columbia during the 1900's and hunting was greatly facilitated by the access provided by linear developments like roads. In the Selkirk population referred to above, illegal hunting combined with road kills could have equaled recruitment within that herd during several years between 1972 and 1983 (950357). Finally, the high numbers of vehicle collisions on Highway 40 between Grand Cache and Hinton probably resulted in a substantial population decline in that small caribou herd (18840).

Although many behavioural effects have been documented for barren-ground caribou of the Central Arctic herd at Prudhoe Bay, population declines have not been documented. Immediately to the east of the Central Arctic herd and in the absence of any significant development, demographic parameters of the Porcupine caribou herd varied significantly from year to year (951784). The variation in demographic parameters could translate into an increasing or a rapidly decreasing population (950658). Our ability to predict the effects of linear developments on herd demographics hinge on a better understanding of the natural variations in herd dynamics.

7.8 Deer

Mule deer and white-tailed deer are ecologically and behaviourally different (820). However, the effects of linear developments on white-tailed deer and mule deer will be dealt with together since broad aspects of the two species' behavioural responses to disturbance are similar (9230).

Linear developments can result in the **disruption of individuals** in a deer population. Deer living alongside development corridors may choose to leave the area when disturbed by humans (e.g., 12860, 9600, 10180, 6510, 8910, 9450). Many factors affect the degree to which humans along these corridors will disrupt deer movements. Hunting tends to make deer more wary of humans and human disturbance of deer along roads is greater in hunted deer populations. In New York State, flight distances for antlered deer, exclusive of spikehorns, were significantly longer in a hunted area than in an unhunted area (9600). In Minnesota, Dorrance et al. (2890) examined the differences in the responses of white-tailed deer to snowmobiles in 2 areas. St. Croix State Park was not hunted but was used heavily by snowmobiles; snowmobiles averaged 10 per day on weekdays and 195 per day on weekends. Dorrance et al. found that deer were displaced from trails during heavy use, but returned quickly once snowmobile use declined during the week. At Mille Lacs Wildlife Management Area where there was hunting but public snowmobiling was not allowed, snowmobile use on trials resulted in increased movement, displacement of deer from trails, and home range abandonment. Deer responded to very low intensities of intrusion by man and vehicles. This study suggests that deer not subjected to hunting can become habituated to snowmobiles to some degree.

In hunted populations, reactions to people on foot tend to be greater than to motorized vehicles. For example, responses of adult female mule deer to people on foot and on snowmobiles were observed during 67 controlled disturbance trials in the winters of 1979 and 1980 on open sagebrush winter ranges in Colorado (12860). Responses by deer to persons on foot were longer in duration, more frequently involved running, and were greater in estimated energy expenditure. Flight distances were 191 m and 133 m from people on foot and snowmobiles, respectively. This study (12860) and another on the heart rate responses of mule deer fawns to snowmobiles (10180) suggest that habituation in hunted populations may not occur.

Deer may also be temporally disturbed along linear developments like roads. In a hunted population in Indiana, the main peak in activity at a lick located 10 m from a road occurred 1-2 hours after sunset in most months (4950). These hours closely corresponded to those hours when deer in the study area were most active and when highway traffic and other human presence were the least active. Use of disturbed sites by radiocollared female desert mule deer in the Belmont and Big Horn Mountains, Arizona increased at night (18010). In a wildlife refuge in the northwestern states, restricting vehicular traffic to periphery roads allowed black-tailed deer to remain diurnally active (13620).

White-tailed deer and mule deer disturbed by human activity exhibit **habitat avoidance** in ways similar to elk. In westcentral Alberta, deer winter habitat utilization was not strongly related to browse availability, but appeared to be related to traditional wintering areas and to human disturbance (12450). In Colorado, fecal pellet counts indicated that deer avoided areas near paved and dirt roads on winter range, particularly those areas within 200 m of roads (13630, 11010). Avoidance was particularly evident in shrubland habitat types; pellet group densities 300-400 m from the road averaged 3.2 times greater than in areas within 100 m of the road. Although differences were not statistically significant, deer tended to avoid heavily-traveled roads more than those less traveled. Winter habitat use of white-tailed deer in mature ponderosa pine-Douglas fir and cottonwood-ponderosa pine communities in northeastern Oregon was investigated using radiotelemetry (1540). The majority of relocations occurred more than 1600 m from main roads. A model predicted that 50 percent, 75%, and 95% of deer use would occur within 44 m, 99 m, and 248 m of cover. In Texas, white-tailed deer also preferred areas near cover and greater than 300 m from ranch roads (2900).

The degree of avoidance or use of a disturbance corridor, may also be associated with the availability of habitat. If feeding areas are available away from the highway, then deer will avoid the right-of-way (12710, 8920). However, if most available forage is along the road corridor as is the case in forested areas, then deer will make use of the area. In the Colorado study (11010), there were 2 study areas, one on the east and one on the west side of the Continental Divide. Deer avoidance of roads was more evident on the east than on the west side. On the east side, deer even avoided dirt roads that were used only by 4-wheel-drive vehicles, trail bikes, and hikers. The authors speculated that this was due to differences in the extent of winter ranges relative to the roads in each study area. On the east side there appeared to be more available winter range. Deer may have avoided roads on the east slope because alternate feeding sites were available, while on the west side, deer may have had to use areas near the road to avoid malnutrition (11010).

Avoidance of roads is likely a characteristic of hunted populations. In the Mendocino National Forest, California, increased vehicular traffic during the hunting season apparently caused displacement of study deer whose usual home ranges during that time of year were within 200 m of secondary roads (2580). Deer can readily habituate to disturbance corridors, most notably in protected areas like national parks (4120). Deer in these situations do not appear to avoid roads in the same way. Habituation may also occur in other circumstances. In Wyoming, Ward et al. (9940) describe mule deer using areas within 100 m of Interstate 80.

One study relating summer habitat use by deer to road densities was located (10610). Thomas et al. (11590) used Perry and Overly's data (10610) to develop a relationship between road density and habitat effectiveness. A 20% loss in habitat effectiveness occurred when road densities were about 2 miles/mi^2 (1.24 km/km^2) of summer habitat. Extrapolations of the data predicted that at road densities of 6 miles/mi^2 (3.72 km/km^2) habitat effectiveness would decline by 50-95% depending on the road type (11590).

Linear developments can act as barriers or filters disrupting the movements of individuals within their home ranges. As with other ungulates, the presence of a structure like a raised pipeline or a berm that impede a deer’s line of sight seems more important than the structure's actual size. In northeastern Alberta, Penner (94313) found that 19% of deer (n=114) were deflected by roads and/or pipelines. Pipeline heights at point of crossing were in the 1-1.4 m range in Penner’s study area. Also working in northeastern Alberta, Kansas and Raine (18830) found that deer crossed secondary roads in all cases (n=103) while they were deflected by main roads on 3 of 84 (4%) occasions. Of 731 deer interactions with above-ground pipe, 650 (89%) crossed directly, 41 (6%) were deflected up to 100 m before crossing, and 19 (3%) were deflected completely. Deer were found not to cross under pipes that had a pipe to ground clearance of less than 0.6 m. Based on the proportion of pipe heights available, deer tended to avoid crossing at heights of 0.5-0.9 m at a greater frequency than expected (18830). Deer distribution did not appear to be affected by the disturbance corridors in both studies. Penner stated that deer continued to inhabit the area in the immediate vicinity of the developments and while roads and pipelines were impediments to movements, they did not prevent successful crossings (94313).

Pipelines under construction can also act as barriers or filters to deer movements. Morgantini carried out several studies on pipeline construction and its effect on deer movements (3110, 3130, 3140, 3160, 3170, 3210). Again, size and clearance of the pipeline were important determinants in deer crossing success. When a 109 cm diameter pipe was lying on the ground, deer crossed successfully in just 39% of attempts (3110). Deer crossed the right-of-way whenever openings in the pipe stringing were encountered. However, once the pipe was raised up on blocks (98 cm clearance), the success rate increased to 62% (3160, 3110). Deer were most affected by 2 or more welded pipe strings. In one study, 71% of encounters with 2 welded pipe strings (6, 17 cm diameter) resulted in failure to cross (3140). The filter effect resulted from the presence of multiple pipe strings, their height and distance apart, and the presence of dirt berms and sometimes ditches. The effects of temporary barriers like pipelines under construction did not appear to be severe. The distribution of deer did not appear to be altered by pipeline construction in westcentral Alberta when snow depths were 5 to 30 cm (3130). Morgantini felt in that case that the overt response by deer to pipeline construction might reflect habituation to human activities (3130).

Impacts of berms and slash piles are limited if there are breaks and openings. In western Montana, deer preferred cutblocks in which logging slash was not a barrier to movement (2290). On 1 pipeline construction project in westcentral Alberta, deer failed to cross berms in 22% of all encounters (3140). In most cases, failure to cross was related to the presence of strings of welded pipe lying beside the berm. Significant differences were found between the average height of dirt berms where deer entered the right-of-way and where they crossed the berm; deer selected for significantly lower crossing points. Visibility across a berm may be one of the major factors affecting the willingness of deer to cross at a particular point (3140).

When disturbance corridors cross migration routes, deer migration can be blocked (8810, 9020). In Idaho, the construction of Interstate 80 across a migration route of mule deer without a means of allowing deer passage blocked most of the deer population from reaching winter range (6310). The Idaho Department of Fish and Game was forced to provide supplemental feed during most winters.

Environmental conditions affect the degree of impact that these developments have on deer migrations. Track counts and movements of radio collared mule deer were monitored near Maybe Canyon Mine and a phosphate processing plant north of Soda Springs, Idaho for 5 years to determine whether mine pits and associated facilities hindered deer migration (18300). Movements of migrating deer differed in years of different snowfall. Deer avoided the development during a year of low snow accumulation when they could move south of the development, but took the most direct route through the development when snow accumulation was high. Only in the year of most rapid and highest accumulation of snow was the movement of deer through Maybe Canyon Mine delayed (18300). Morgantini found that distribution of deer did not appear to be altered by pipeline construction in westcentral Alberta when snow depths were 5 to 30 cm (3130). Deeper snow affects deer distribution naturally (950327), and the effects of linear developments like raised pipelines would change with increasing snow depth (18830).

Disturbance corridors can cause **habitat disruption** through the direct removal of habitat. Roads dissect and eliminate a vast amount of deer habitat. Reed (8810) calculated that in the western U.S., interstate, rural, and county highways occupy 11, 3, and 2 ha of land per kilometre, respectively. Two interstate highways that traverse the geographic range of mule deer pre-empt about 53,000 ha of land (8810). In addition, the locations of these disturbance corridors further exacerbate the problem since they are frequently placed in valley bottoms or along south-facing aspects through the mountains, the same general locations for deer migration routes and deer winter ranges. By the end of 1981, there were 6.2 million kilometres of improved public roads and another 161,000 kilometres of primitive or unimproved roads in the United States; about 84% of the improved roads were in rural areas (510). Improved roads accounted for 1.1% of the entire country's land surface in 1981 or the equivalent of the states of Rhode Island, New Hampshire, Vermont, Massachusetts, and Connecticut combined. At that time, new roads were being built at a rate of 18,000 km per year (510).

In addition, linear corridors such as roads can disrupt habitat indirectly through the introduction of exotic plants, and pollutants like dust, salt, and automobile emissions. For example, mule deer forage collected from roadsides in Rocky Mountain National Park, Colorado, contained lead (Pb) concentrations ranging from 0.8 to 50 µg/g. Concentrations were inversely correlated with distance from the roadway. Equations developed to estimate deer absorption of Pb from contaminated roadside vegetation indicated that deer in some age classes needed only to consume 1.4% of their daily intake of forage from roadsides before consuming excessive amounts of Pb (12940).

Linear developments may result in **habitat enhancement** for deer, depending on the type of development and the habitat through which the development passes. Roadsides, and transmission and pipeline corridors through forested habitats can add significantly to the food resources available to deer (e.g., 9100, 10160, 13550, 14000). However, the degree to which these habitats are used (e.g., nocturnal vs. diurnal) depends on whether or not deer are hunted in the area. In eastern and western Montana, mule deer and white-tailed deer pellet-group distributions suggested that animals entered cutblocks in search of better quality or greater quantities of forage (2290). However, the willingness of animals to enter openings was influenced by a requirement for security during the feeding period and was locally modified by past experiences. Deer preferred cutblocks with cover in the opening except where such cover inhibited forage growth (2290).

Linear developments can contribute significantly to **direct mortality** in deer populations. Deer are likely the most frequently-killed large mammal along North America's roads. In a nation-wide survey of the U.S.A., Romin and Bissonette (650) estimated that the national deer road kill for 1991 conservatively totaled at least 500,000 deer. Deer road kills had increased during 1982-1991 in 26 of 29 states that had suitable trend data. These increases were likely caused by both increases in the numbers of roads (510) and increases in deer populations (e.g., 6320). Road kills frequently rank as the largest mortality factor for deer populations after human hunting (e.g., 2380, 9090, 12710, 950317). In many eastern American states where white-tailed deer populations are high, road kill figures reflect the extent of the highway system and traffic volume (e.g., 490, 10300). However, in South Dakota, no relationship was found between traffic volume and deer kills along an interstate highway (15480).

Reported annual road kill rates are quite variable. During 14 months, 286 white-tailed deer were killed by vehicles on an 8 mile (12.8 km) section of Interstate 80 in central Pennsylvania (12710), a kill rate of 19.3 deer/km/year. Along a 3 mile (4.8 km) stretch of secondary highway in California, mule deer kill rates of 3.7 and 4.8/km/year were recorded during spring and fall migrations, respectively (5860). Kill rates of 1.2 deer/km/year were determined for 2 interstate highways in Pennsylvania (6860, 5000). In Kootenay National Park over a 10-year period, 1978 to 1987, the mean annual kill-rate for white-tailed deer on the Kootenay Parkway was 0.6/km/yr.

Patterns in collisions between vehicles and deer are likely different on different types of roads and in different environments, so care must be exercised in describing generalizations regarding deer-vehicle collisions. However, collisions tend not to be random, but are aggregated in time and space. Most deer-vehicle accidents occur in the early morning or late afternoon and evening hours, typically around dawn and sunset (e.g., 10300, 3880). These are peak collision periods probably because deer are most active during these periods, and driver visibility is poor at that time (820). In many areas, more deer are killed during the spring and fall than at other times of the year (e.g., 3880, 6300, 8450, 8560, 10300, 12710). The fall mortality peak may be caused by deer, particularly males, increasing their movements during the rut (8560), and possibly also due to increased disturbance of deer during hunting seasons (6860). In spring, road rights-of-way tend to green-up sooner and these areas of new green growth are attractive to deer (6860).

High deer-vehicle collision areas are also clumped spatially. The relationship between deer activity and deer-automobile collisions are functions of highway location relative to deer requisites such as feeding and resting sites and to the relative availability of feeding areas other than rights-of-way (4920, 8920, 15480). Deer were killed more often than expected adjacent to shelterbelts and less often than expected adjacent to grassland habitats along Interstate 29 in South Dakota (15480). Similarly, on a 500 km section of Interstate 80 in Pennsylvania, high deer mortality occurred where fences were located at the edge of a wooded area or within 25 yd (23 m) of the nearest wooded area. The lowest deer mortality occurred where a fence was located over 25 yd (23 m) from the nearest wooded area and low mortality also occurred where the fence was located within the woods (6860). On Interstate 80 in Pennsylvania but along a 8 mile (12.8 km) section where many deer were killed (12710), white-tailed deer mortality was highest in sections of highway that lay in troughs, and through flat areas where both sides of the highway and the median strip provided good pasture. Along secondary highways, kills were significantly correlated with areas of vegetation no more than 2 m in height (2170).

In Kootenay National Park the greatest collision frequencies corresponded to the locations and periods (seasonal and diurnal) of heaviest ungulate use of the Parkway corridor and right-of-way and not necessarily to periods of greatest traffic volume. Traffic volume was a factor, however, when high volumes corresponded to the critical periods of ungulate use (580).

Road width may have an impact on the number of deer-vehicle collisions. Annual totals of white-tailed deer killed by automobiles in a northern deer wintering area in Michigan's Mackinac County were compiled for a 13 year period. US-2, a 2-lane highway, intersects a 5-mile (9 km) stretch of this wintering area. In 1963, Interstate 75 was constructed roughly parallel to US-2 and about 0.25 mile (0.4 km) east of it. The interstate highway also intersected the wintering area. In 1964, car-deer kills increased by about 500% over the average of the previous 4 years (4940). Mortality levels in 1972 were twice that of the pre-interstate annual mortality figures.

Few data are available relating road kills, the effects of vehicular speed, and vehicle types. In Michigan, deer-vehicle collisions were most common at speeds of 80-95 km/h (10300). On secondary highways in Pennsylvania (2170), posted speed limits showed significant negative correlation with the location of road kills. The authors hypothesized that either deer crossed highways less frequently where vehicles were traveling faster or more likely that posted speed limits had little relationship to the actual speed traveled. Just 1 reference was found regarding the possible effects of vehicle type on road kills. In a detailed study of road kills in Kootenay National Park, Poll (580) speculated that large trucks may be responsible for a disproportionate number of wildlife-vehicle accidents on the main highway through the Park.

Published studies on the sex and age breakdown of the road kill are equivocal. Many studies did not provide a breakdown of the kill by sex and age. On Interstate 80 in Pennsylvania, mortality among fawns and yearlings was not significantly different between the sexes, but among adults many more females than males were killed (12710). In South Dakota, females were killed more often throughout the year except in November when more males were killed (15480). Road-killed deer in western Montana were more often fawns or older (7+ years old) animals than were deer killed by predators (8330). In addition, road-killed deer were more frequently in poor condition than deer killed by predators. The sex and age structure of all deer populations mentioned above were not known, so the degree to which certain sex and age classes of deer are susceptible to mortality on roads cannot be determined.

Indirect mortality occurs as a result of linear developments because these development corridors allow human access into areas for hunting (e.g., 11570, 94303). Linear developments, more than any other factor, affect the distribution of hunters and therefore, the distribution of the hunter kill. In West Virginia, 3 of the 6 most important variables in determining hunter distribution were trails, camping or parking sites, and roads (10470). The number of hunters that visited an area decreased with distance from a trail, camping or parking site, or road. In north-central Minnesota, 143 deer >6 months old were radiocollared and monitored. Mortality during the hunting season was 2-4 times higher for deer residing <0.2 km from a road than for those >0.8 km from a road (5890). Increased access can result in overharvest of local deer populations. In Quebec, deer hunt data show that continual declines in the harvest were inversely proportional to the distance from several large urban centres. Major access routes radiating from these urban centres into deer range seemed to direct the flow of hunters (2420). Of course, legal hunters aren't the only beneficiaries of better access. During an intensive 5½-year study of a deer population in New York State, the cause of death was documented for 108 deer; legal hunting accounted for 56.5 % and illegal hunting 18.5 % of all kills (9090).

Population effects may occur as a result of hunting mortality associated with linear developments. For example, in an intensively farmed area of Illinois, fragmentation of remaining cover affected deer survival during hunting seasons (13590). Deer numbers increased on protected land and in more lightly-hunted larger forests, but could be temporarily extirpated in smaller wood lots.

7.9 Moose

Individual disruption of moose may occur along development corridors. Intuitively, this disturbance is likely most prevalent in hunted populations, but it may also occur within protected areas. When evaluating the effects of human activities on moose along the Mount McKinley Road in Denali National Park, Tracy (950094) found a positive correlation between proximity to the Mount McKinley Road and the strength of moose disturbance responses. Within 20 m of the road, 50% of moose showed no reaction to buses, 20% showed a mild reaction, and 29% showed a strong reaction. Tracy also showed that the response of moose to disturbance was very subtle; they sometimes didn't look up at the bus but would graze off into cover.

Moose **avoid habitat** in the vicinity of roads because of human activity associated with them. Linear developments like roads provide access for humans using motorized and non-motorized means. Again, this is most evident in hunted populations. A hunted moose population near Rochester, Alberta was distributed significantly further from roads between November through January than would be expected by chance over a 13-year period (19240). In a study of moose distribution in an area of oil and gas development in northwestern Alberta, use of habitat near roads was significantly reduced compared to control areas away from a road (270). Moose use of browse along transects within 200 m of roads was 55% less than on transects 200 to 400 m from roads. In this case, particularly heavy hunting pressure along the roads probably caused the observed effect (270). Denniston (19200) found that moose abandoned an area in Montana when a highway was being constructed.

Human activity associated with pipelines, cutlines, and seismic lines has the potential to displace moose. During 2 pipeline construction projects, Morgantini (3130, 3140) documented avoidance of pipeline rights-of-way during the construction periods. In 1 of these cases (3140), this reduction appeared to be restricted to a particular portion of the pipeline associated with a 1.0 to 2.5 m tall slash pile that paralleled the right-of-way. Avoidance appeared to be limited to the construction period because 1 year after construction avoidance of the pipeline right-of-way was not documented. In an earlier study, Morgantini (3110) did not find a significant change in the distribution of moose relative to construction activity on a pipeline right-of-way in western Alberta. According to Horesji (19210), moose were less likely to be found within 1 km of seismic lines when the lines had human activity on them. In the same study, vehicle activity within 250 m of moose in open terrain often caused them to leave the vicinity (19210). Moose distribution within a 15-km corridor on either side of the TransAlaska Pipeline was uniform indicating neither an avoidance of or a preference for the pipeline corridor (600).

Avoidance of disturbance corridors because of human activity may also occur in protected areas. In Denali National Park, number of vehicles per day increased 50% from 1973-74 to 1983-83 and moose sightings per trip declined 72% during the same period (9320). Following cross-country ski development in Elk Island National Park, the proportion of moose within 500 m of cross-country ski trails decreased from that recorded before ski trail development (3390). Moose densities were lower near heavily-used trails than elsewhere in the park.

Linear developments such as pipelines may act as barriers or filters to movement of moose. Several studies have examined the effects of pipelines on moose populations. Buried pipelines were not a barrier if large berms were not associated with them. Elevated pipelines constituted a barrier to movement if the ground clearance under the pipe was too low for moose to travel underneath, and too high to jump over. Of 1,068 crossings under the TransAlaska Pipeline, 57% were in areas where the pipe was between 6 (1.8 m) and 8 feet (2.4 m) off the ground (19220). Moose were deflected when ground clearance was less than 4 feet (1.2 m). However, migratory moose were generally successful in crossing a 117 km-long elevated portion of that pipeline (7090). The Primrose Production Pipeline in northeastern Alberta is elevated on average 180 cm off the ground. Overall, 18 of 20 moose that attempted to cross the pipeline did so directly, 1 was deflected about
25 m and another was deflected about 60 m before crossing (320). Pipe-to-ground clearances where moose crossed under the pipe were 194 cm, whereas sites where moose were deflected had clearances averaging 132 cm (n=2). Sites where moose crossed over the pipe had, on average, 37 cm of ground clearance. On the Cold Lake Production Project, 9 of 14 moose trails that encountered an elevated pipeline crossed directly, 2 were deflected less than 25 m before crossing and 3 did not cross (180^{o} deflection) (18830). Mean clearance of the pipe at moose crossing points was higher (142 cm) than the average height of the pipe overall (99 cm). In the same area, Penner (94313) found that only 1 of 23 moose successfully crossed an elevated pipeline. In addition, he documented 7 of 23 moose trails that demonstrated avoidance of roads and/or pipelines. Kansas and Raine (18830) stated in their report that the elevated pipeline at Cold Lake had a greater barrier effect on moose than the TransAlaska Pipeline probably because of the lower average height of the pipeline in their study.

Many of the studies cited above occurred during winters of relatively low snow depths, and authors raised concerns regarding reduced ground to pipe clearance when snow depths increased. Increased snow depths would reduce clearance under raised pipelines and would increase the number of deflections and failed crossing attempts (e.g., 19220).

Pipelines under construction can have a significant filter effect. During construction of the Edson Mainline Loop, just 41% of 32 groups (1 or more moose) that approached the 106-cm diameter pipe, either as strung pipe on the ground or as welded pipe on blocks, crossed successfully (3110). The success rate for moose crossing the welded pipe alone was 31%. The welded pipe varied between 60 and 180 cm in ground clearance. Since the length of unbroken pipe off the ground (lead-point welding to lead-point laying) averaged 24 km (range 19-33), pipeline construction disrupted the movements of moose in a relatively large area along the pipeline route for days at a time. Construction of the Hanlan and Brazeau gas pipelines did not result in the same filter effects for moose (3140). Multiple pipes of smaller diameters (9 to 46 cm diameter) were involved. Thirty-two of 39 groups crossed the pipeline(s) successfully. Mean clearance of the pipes at successful crossings was 24 cm, while at unsuccessful crossing points mean clearance was 34 cm. In addition, all unsuccessful crossing attempts occurred where there were at least 2 welded pipe strings on the right-of-way separated by 90 cm.

Several studies in Alberta and elsewhere have shown that berms of snow and/or earth, and slash piles associated with pipelines, roads, and railways could have a significant effect on moose movements. Sight lines at berms, height of berms, and berm composition seemed to be important attributes that affected moose movements over them. Slash berms 1-2.5 m high and 1-3 m wide were implicated as a possible cause for the observed reduction in moose activity along 1 portion of a pipeline under construction in western Alberta (3140). Along this same pipeline, moose successfully crossed dirt berms averaging 88 cm in height, 51 of 56 times. The average height of the berm at failed crossing attempts was 103 cm and in 2 of the cases involved 3 strings of pipe in addition to a berm 129 cm high. Moose successfully crossed all slash (n=2) and snow (n=11) berms encountered along the pipeline, but always crossed in areas where the height was lower than the average height of the berm. During another pipeline construction project in the same area, moose successfully crossed dirt berms 16 of 17 times, but in most cases selected crossing points where an opening was present or where the berm was lowest (3110). Moose were deflected by snow berms averaging 65 cm on primary roads in northeastern Alberta (18830). Along the Primrose Production Pipeline, snow berms up to 1.5 m in height were an obstacle for some moose (320). In cutblocks in northeastern Alberta, Usher (19250) documented moose trails paralleling windrows and crossing through major breaks in them.

Linear corridors may create (**habitat enhancement**) or remove habitat (**habitat disruption**) for moose depending on the habitat types they are traversing. Any linear development through a closed forest will open up the canopy, creating edges that encourage the growth of shrubs, preferred browse species for moose (e.g., 4180, 2600). Conversely, corridors that traverse riparian areas -- habitat that is already good for foraging moose -- remove habitat, reducing the carrying capacity of the landscape for moose. The degree of impact is proportional to the width and length of the disturbance corridor. Freeways and paved primary highways remove more habitat than narrow country roads and truck trails. A 20 m wide corridor in riparian habitat removes 1 km^2 of moose habitat for every 500 m of linear distance. As is the case with other ungulates, this impact is probably minor in comparison with avoidance and mortality impacts associated with disturbance corridors.

Linear corridors may also be considered habitat enhancement if these corridors act as travel corridors for moose in otherwise unsuitable habitat (e.g., 4800, 5330, 19200). Ease of movement along them make them attractive travel routes for moose in habitats with dense understories or otherwise impenetrable vegetation. This is particularly true in winter in northern climates where deep snow hinder moose movements, and these rights-of-way are cleared of snow (e.g., 18830, 320, 5060). However, mortality associated with the use of these corridors for travel probably more than offset any benefits moose may derive from using them (see below).

The use of salt on road surfaces also attract moose to road rights-of-way (e.g., 5760, 6170, 4100, 4930). Salt draining from road surfaces accumulates in roadside ponds that become focal points of activity during summer and fall, particularly for female moose and their calves (1630). Again benefits from salt intake are offset by increased mortality as a result of moose collisions.

Linear developments are sources of **direct mortality** for moose. Collisions with vehicles and trains are the greatest source of human-related mortality after hunting. Vehicle collisions have been documented from British Columbia to Newfoundland, Minnesota, Alaska, Norway, and Sweden, wherever moose habitat is traversed by these disturbance corridors. The numbers of moose killed can be substantial. For example, between 1984 and 1989, an average of 216 moose was killed each year on Alaska's roads (4800). The number of moose annually killed on railways in Norway averaged about 500 in the late 1980's (5090). In a 3-year period, Pat Wells, a Canadian Pacific Railway engineer, documented 33 moose killed by trains over a 198 km stretch of railway between Field and Revelstoke, British Columbia (951644).

Road mortality appeared to be related to traffic volumes (6170), and speed (e.g., 4800, 5380). However, in Kootenay National Park in British Columbia, greatest collision frequencies corresponded to the locations and periods of heaviest ungulate use of the road corridor and not necessarily to periods of greatest traffic volume (580). Traffic volume was a factor in the park when high volumes corresponded with periods of high ungulate use. In Minnesota, vehicle traffic volume explained 59% of the monthly variation in the frequency of moose-vehicle collisions (4420). However, train speed did not seem to have an effect on train collision rates in Alaska (5250). Conversely, Wells stated that train speed did affect collision rates between trains and moose in the Rocky Mountains (951644).

Season also influenced the number of moose kills on roads and railways. In northern areas, collisions were usually clumped in the winter months and typically were more severe where these disturbance corridors crossed moose winter range during deep snow conditions (e.g., 4800). Of 33 moose killed by trains between Field and Revelstoke, 31 were killed between November and March (951644). In Alaska, a high proportion of railway accidents occurred when snow depths exceeded 100 cm (5060). In southern Sweden, more traffic accidents occurred during calving in the spring and during the rut in the fall (5210). Time of day was also a factor in collision rates. Most collisions occurred at dusk and dawn, and were more frequent at night than during daylight hours (e.g., 4420, 5090).

Indirect mortality as a result of linear developments in moose habitat has also been documented. Moose attracted to or crossing a disturbance corridor may suffer greater mortality than elsewhere within their home ranges. Mortality often occurs as a result of hunting. In New Brunswick, Boer (2560) found that hunter kills of moose were highly clumped; 92% of moose were killed within 1 km of forest roads. Major access routes radiating from population centres seemed to direct the flow of hunters in Quebec (2420). Overharvests of moose occurred in areas with greater access (2420). Lynch (19260) documented increased moose harvests in an area of intensive oil and gas development with associated increases in access. Most hunting activity occurred within 1.6 km of roads and most successful hunters were using all-terrain vehicles.

The **population effects** associated with disturbance corridors were variable. In Minnesota, collisions with railways and vehicles equaled 9-11% of the total annual harvest during 1993 and 1994, and less than 1% of the regional moose population (4420). On the Kenai Peninsula, where the mean annual survival rate of female moose was 0.92, the mean annual mortality rate as a result of collisions with vehicles was 0.04 while the annual hunting mortality rate was just 0.01 (11460). In isolation these mortality rates probably would not result in population declines. In Laurentides Park, Quebec, road-killed moose killed represented 15 to 20% of the moose population living near the road (6170). In Kootenay National Park, current levels of mortality along the highway may be contributing to the continued decline of the moose population in this protected area (580). Population reductions in Alberta were attributed to increases in access associated with oil and gas development (19260). Similarly, greater numbers of roads and improved accessibility around gas plants were cited as probable causes for reduced moose densities relative to inaccessible control areas (270). As a word of caution regarding the importance of reported human-caused mortality rates related to roads, Bangs et al. (11460) found that human-related mortality along roads occurred at nearly twice the rate reported by authorities.

7.10 Mountain Goat

The effects of linear developments on mountain goats are not well-documented relative to almost all other North American ungulates.

Disruption of individual mountain goats has been documented in a number of instances, although the degree of disruption was quite variable between studies. Penner examined the effects of noise stimuli representative of petroleum exploration activities on forest-dwelling goats in Alberta (950813). The project was divided into 3 phases: 1) experimental habituation, 2) seismic exploration, and 3) drilling of an exploratory natural gas well. In the first phase, goats appeared to accept or tolerate indirect and persistent noise disturbance based on observations of insignificant changes in behaviour, activity, and habitat use. Habituation achieved an increase in the goats' awareness of introduced acoustic stimuli and human presence without causing adverse responses. During seismic exploration, goats maintained typical patterns of daily activity and habitat use in comparison to baseline data. The results of the first 2 phases suggested that goats would tolerate the potentially disturbing noise stimuli that would accompany seismic activities; that is, their behaviour would not be disrupted by development activity. Overall, it appeared that goats habituated to predictable, continuous stimuli, but were disturbed by unpredictable, sudden stimuli. Nannies were more sensitive to stimuli of all kinds during the kidding and post-kidding seasons.

Recreational impacts on mountain goats in Colorado were assessed by simulated disturbances (950855). Goat-recreationist interactions had a negligible effect on mountain goat activities. Similar to Penner's (950813) observations, flight distance (the distance a recreationist could approach the goats before escape behavior was initiated) was greatest in nanny-subadult groups, and lowest in juvenile, male, and mixed groups. Mean flight distance for all groups (n=345) was 82.6 m. Flight intensity, a measure of escape behaviour intensity, was greatest in juveniles and nanny subadult groups, and lowest in male and mixed groups. Mean flight intensity for all groups (n=345) was a slow walk away from the disturbance.

Other authors have noted a lack of overt behavioural responses to disturbances. For example, Chadwick (4210) recorded goats on hillsides within 91-152 m of roads. Occasional noise from vehicle traffic below caused temporary suspension of activity, but immediate movements out of the area were not documented. In the same study, he observed goat reactions to sonic booms and dynamite blasting and found that although individuals became alert, they resumed their previous activities in 1-3 minutes.

The effects of helicopters in association with development activity elicited the strong disturbance responses from goats. In northwestern British Columbia (950897), the behavioural responses of more than 800 mountain goats (195 social groups) were recorded during hydroelectric exploration activities, primarily helicopter-based. More than 80% (n=667) of the observed goats elicited some form of behavioural stress response, with 33% (n=265) displaying a severe flight response to local rock or plant cover. As expected, significant correlations existed between distance of disturbance, geographic area, cover availability, and degree of awareness. Responses were stimulated primarily by auditory and secondarily by visual cues. In contrast to the studies mentioned above, goats in this study appeared to be equally as nervous and as highly excitable in responses to helicopter, airplane, and human activity. The researchers also noted that goats altered their diurnal feeding regime near an active drilling camp. The goats shifted to a crepuscular foraging pattern and decreased use of less precipitous and more densely vegetated slopes and burn areas near the drilling sites. Early morning human-induced disturbances (usually helicopter flights) cut short foraging patterns of goats in these areas. At another exploration site where activity was centred near the bottom of the canyon, goats moved out of the canyon and occupied the woodlands above.

Several other researchers have observed strong reactions to helicopters by mountain goats. In Prism's review of how petroleum industry operations affect wildlife (563), W.H. Hall (pers. commun.) reported that helicopters flying at an altitude of 150 m caused goats to scatter, and that goats continued to climb even after helicopters left the area. Chadwick (4210) noted that goats ran at high speed and took refuge in escape terrain when helicopters were in the vicinity. Joslin conducted a study of mountain goats subjected to disturbance from a heli-seismic exploration program (90825). Goats in that study moved away from human activity, and used topographic relief to screen themselves from line-of-sight disturbance. The distance between the helicopter and goats at Caw Ridge, Alberta was the most important variable affecting goat behavior (951664). When helicopters were <500 m away from goats, 85% of groups walked or ran at least 100 m or remained alert for more than 10 minutes (n=20)

Habitat avoidance has been documented in goat populations disturbed by development activities. In some cases the displacement of goats was temporary. For example, in northwestern British Columbia (950897), repeated aerial and ground follow-up surveys documented temporary range abandonment and changing observability indices (habitat use and activity patterns) associated with areas of intense exploration activity. During a period of drilling activity, goats moved 1-3 km away from slopes within 100 m of a drilling camp. This move coincided with the camp's installation. However, within 2 weeks of the camp's shutdown, the goats reoccupied the vacated areas and remained there throughout the following fall and winter. Chadwick (4210) also documented short-term displacement of goats in areas subject to road construction and blasting 10-15 times per day. He noted the reappearance of some goats on days when noise was absent. Similarly, Hall (pers. commun., in 563) found that during test coring for coal exploration on Mount Hamell in Alberta, goats no longer utilized upper cliff areas near the drilling sites during the day. Coal company personnel stated that goats were found at these higher altitudes in the morning but once activity began the animals moved to the valley bottoms.

Return to previously-used habitats may not always occur after the disturbance is removed. Again in Prism's review (563), Hall (pers. commun.) recorded range abandonment by about 40 goats from a hunted population of 70 in the Syncline Hills after an intensive trapping effort removed 12 goats for transplant. He suspected that the displaced goats had joined an adjacent herd. Conversely, goats did not abandon their traditional home ranges, although they did redistribute themselves within their home ranges to avoid disturbance during a heli-seismic exploration program in Montana (950825).

Penner (950813) also documented a change in habitat use by goats when an exploratory gas well was placed about 2.1 km from their traditional winter range. During the drilling program, the nursery band failed to move to their traditional winter range, although there was no behavioural evidence to indicate that noise disturbance was a factor. In December, the nursery band made several trips to the northern end of their summer range in what could be interpreted as attempts to move to their winter range. However, they turned back as a cohesive group in each case. The noise levels on the winter range at the time were within the range of introduced noise disturbance that goats were habituated to earlier in the same study (950813). In contrast to the nursery herd, both adult males in the population used the winter range during the drilling program. Whether the nanny group returned to their traditional winter range the following winter when the drill rig was absent was not indicated.

Goats will cross disturbance corridors as large as 2-lane highways to access mineral licks. Singer conducted a study of mountain goats crossing a highway to visit a natural mineral lick in Glacier Park, Montana (12690). Eighty-seven successful crossings of the highway involving 692 mountain goats were observed, and an estimated 812 crossings occurred during the lick season. Crossing success was associated with the size of groups; all groups (2-55 goats) were more successful than individuals. Crossing success was also associated with sex and age of the group leader. The most successful groups were led by an adult nanny with a kid at her side. Successful highway crossings after July 1 were most often crepuscular. Goats appear to behave in a similar fashion at the Mount

Kerkeslin mineral lick along the Icefields Parkway in Jasper National Park (personal observation).

As is the case with most species of wildlife, **direct mortality** for mountain goats occurs as a result of collisions with vehicles. Damas and Smith (3760) categorized vehicular accidents to represent mortality in excess of 50% of annual increment of a mountain goat population in Glacier National Park, British Columbia. However in the same report, the effects of vehicular accidents on goat populations were not mentioned for Mount Revelstoke, Kootenay, Banff, and Jasper National Parks, and were rated as minor in Yoho National Park. Singer (12690) stated that few mountain goats (0-2) were hit by vehicles while crossing Highway 2 in Glacier National Park, Montana each year, although a minimum of 89 goats, and possibly as many as 100-200 goats used the lick annually. The British Columbia Wildlife Accident Reporting System 1994 annual report does not list any goat mortalities (950797).

The most common cause of **indirect mortality** as a result of linear corridors is hunting and poaching. Disturbance corridors, principally roads, result in access and access has both historically and currently resulted in goat mortality. In the 1940's and 50's in Idaho, hunters converged on accessible goat herds (950835). In British Columbia, increased access resulted in many mountain goat populations being overhunted prior to the 1980's (1488). Over-exploitation following increasing access was singled out as the cause of drastic declines of the goat population in the East Kootenay area of British Columbia (950944). In northeastern British Columbia, there was a clear relationship between access and goat numbers prior to 1977 (950835). According to Pendergast and Bindernagel (950845), nowhere in the coal block, an area of northeastern British Columbia undergoing exploration and development for coal, was there a healthy goat population with nearby road access. Variability in access continues to contribute to differing harvest rates throughout British Columbia.

Population effects as a result of linear developments have not been quantified in most studies of mountain goat disturbance. In British Columbia, and specifically in the East Kootenay region, increased access was singled out as the cause of overhunting in many mountain goat populations (1488, 950944).

However, 1 study implicated heli-seismic activity as a major contributor to changes in the demographics of a goat population. Joslin (950825) conducted a 5-year mountain goat study along the east slope of Montana's Rocky Mountains to quantify population parameters and to monitor the effects of a helicopter-supported seismic program. The study included 2 distinct goat populations. Prior to the initiation of the seismic exploration, these 2 populations had different demographics. One had kid production 40% lower than the other and Joslin attributed these differences to the levels of disturbance to which each population was exposed. The population with higher kid production was inaccessible while habitat of the population with low kid production was much more heavily utilized by humans (more motorized access and use). About 579 km of seismic lines were shot in goat habitat. The effects of the helicopter-based seismic activity were different for the 2 populations. The adult female population trend was stable for the inaccessible segment, but declined significantly in the previously-disturbed population. Kid-nanny ratios in both populations dropped significantly during peak heli-seismic activity. However, after the cessation of seismic activity, decline in the kid-nanny ratios in the inaccessible population was reversed, while kid production, number of kids, and the number of nannies continued to decline in the previously-disturbed population. Joslin (950825) speculated that the continued decline in the previously-disturbed population may have been due to the long-term additive effects of several stressors on that population.

Joslin (950825) looked at the possibility that other factors influenced the goat populations' demographics coincident with the seismic work. Weather, hunter harvest, livestock grazing, and timber harvest were ruled out but it was noted that broncho-pneumonia might have been a contributing factor in the observed changes in demographics. The drop in mountain goat production parallelled the pattern of bighorn sheep decline due to a pneumonia die-off. Two possible cases of this stress-related respiratory disease in goats were identified on the Rocky Mountain Front (but not in the study areas). The author concluded that if this stress-related pneumonia was latent in mountain goats along the Rocky Mountain Front, then it was possible that the disease and the stress-inducing effects of seismic activity could have acted in concert to cause the observed decline in females and kid production (950825).

For mountain goats, **habituation** to disturbance seems to be dependent on the extent of the disturbances involved and previous disturbance history. Penner (950813) demonstrated that mountain goats can accommodate the effects of a ground-based seismic program, at least if there are no other stressors present. The winter drilling program did not appear to have an impact on the health and survival of that goat herd. Joslin's study (950825) in particular, as well as the study of Foster and Rahs (950897), would indicate that the effects of disturbance on goats are additive if the levels of disturbance are high (such as those associated with helicopters). In Joslin's study (950825), the correlation between goat productivity and seismic activity in previous years and the lack of recovery in the population where the seismic disturbance appeared to be additive to the other stressors already present suggest that stress can accumulate over time. Mountain goats in Foster and Rahs study (950897) did not appear to habituate to the disturbances associated with hydroelectric development.

7.11 Mountain Sheep

Disruption of individuals has been documented in a number of mountain sheep studies. Differences between these studies stem primarily from the level of habituation to disturbance that each study herd had developed.

Sheep can become habituated to humans and disturbances along linear developments. A study of the behaviour of wildlife in proximity to roads in Denali National Park found that feeding times and spatial distributions of Dall's sheep were disturbed by traffic and tourists (1220). However, a similar study in the park 10 years later found that wildlife appeared habituated to the road and its associated human elements (9320). Although the number of vehicles per day increased 50% from 1973-74 to 1982-83, sheep sightings remained constant over the 10-year period. Sheep were more readily disturbed during summer when visitors were out of their vehicles than when vehicles alone were present. Habituation appeared to be dependent on frequent exposure to the road. Observations of Dall's sheep groups unsuccessfully attempting to cross the Denali National Park Road during their seasonal migrations have been documented (4680). Sheep occupying ranges away from the road were not frequently exposed to human disturbance along the corridor. These migratory bands were not habituated to traffic, even though the road has been there for more than 50 years.

California bighorn sheep and recreationists were studied in the Sierra Nevada Mountains of California from May through August 1976 (13790). Direct observation of sheep and people, pellet transects, and hiker interviews were used to assess overlap in areas of use and the nature of interactions. Bighorn-human encounters were limited to specific locations and did not adversely affect the bighorn population (13790). Of 20 incidents of observed sheep human/interactions, 6 sheep groups left the area temporarily, possibly because of human disturbance. Approach from above was more likely to elicit a response than approach from below. Several observations suggested that smaller groups of sheep were more susceptible to disturbance than larger groups. In all cases (n=3), solitary ewes left the pass when humans appeared while a group of 5 sheep remained bedded when approached to within 160 m. The authors concluded that sheep were habituated to hikers in this area. Similarly in Banff National Park, Rocky Mountain bighorns did not avoid the Trans-Canada Highway prior to twinning. Increased use of underpasses on the newly-constructed highway over time indicated that sheep were habituating to the new crossing structures (690, 60).

Habituation in bighorn sheep appears to be site-specific (e.g., 3460). This would explain the lack of overt behavioural responses by hunted bighorns to human disturbances on their winter ranges. For example, ewes in the Sheep River Wildlife Sanctuary in southwestern Alberta exhibited very few overt behavioural responses to traffic on a road that passes through their winter range (10080), although these ewes were hunted outside the sanctuary. In southwestern Alberta, the construction of a road and 2 gas wells on Prairie Bluff, a prime winter range for bighorn sheep, did not appear to significantly impact sheep movements or distribution in the short-term (5040). In general, bighorn sheep took little overt notice of activities along the road and were frequently seen grazing within 20 m of the road in spite of its construction, grading, and passing vehicles (5040, 950811). Rams of this herd were hunted in the fall.

However, even habituated bighorn sheep may alter their behaviour in response to human disturbances. Changes in behaviour and movements of desert bighorn sheep in the River Mountains, Nevada, were coincident with construction activities near the population's primary watering site even though these sheep were characterized as having a high degree of habituation to man (8970). The juxtaposition of construction efforts and summer water dependence of bighorn sheep caused a significant shift in use of artificial water sources. Nine of 17 marked ewes altered their watering patterns in response to construction activities. Similarly, changes in watering activity by bighorns in the Buckskin Mountains of Arizona were attributed to construction activities in the immediate vicinity of their watering site (3270). Prior to the onset of construction, sheep came for water in the early morning and late evening. Although this general pattern remained, there was a significant shift toward more frequent watering in the evening and earlier watering in the morning. To avoid human disturbance, bighorns chose to either visit water in the short period between dawn and the onset of construction activities, or they postponed watering activities until the end of the work day. In addition, the lower visitation rate during construction indicated a shift from frequent, opportunistic use of water prior to construction to brief, infrequent use of water during construction. In the Gros Ventre Wilderness Area of Wyoming, bighorn sheep were frequently displaced by recreational users, particularly cross-country skiers (950717).

The effects of previous disturbance can significantly affect the behaviour of bighorn sheep faced with human disturbance. For example, in southeastern Utah, bighorn response was compared between 2 areas with contrasting disturbance histories (4360, 950954, 950956). Prior to this study, Red Canyon (RC) sheep had been exposed to greater levels of hunting pressure and vehicular traffic than had White Canyon (WC) bighorns. To determine if differences in behavioural response to human disturbances existed between RC and WC sheep, groups of sheep were deliberately harassed by vehicles and hikers. Eighty-three percent of harassment trials elicited flight responses from RC sheep as compared to 46% for WC sheep. Average distance fled as a result of harassment was about 2.75 times greater for RC bighorn than those at WC. More intense group wariness was exhibited by RC sheep than WC sheep when they remained in the presence of harassing stimuli. Activity budgets of unhorsed bighorns were similar between areas. However, activity budgets of harassed sheep differed significantly between areas particularly with respect to attention and feeding behaviors. Under harassed conditions, RC bighorns were attentive longer and fed less than did WC sheep.

In contrast to the behavioural responses of bighorn sheep to ground-based disturbances, sheep often respond dramatically to helicopter and fixed-wing aircraft disturbance. Several studies have examined the effects of helicopter overflights on sheep. Again, habituation seems to play a role in reducing escape behaviour, although the flight paths of aircraft also appear to play an important role. During helicopter surveys of sheep in California, significantly more animals abandoned survey blocks and moved farther during helicopter surveys than on non-survey days throughout the year (910). Likewise, mountain sheep changed the vegetation type in which they occurred more often after than before helicopter surveys. Helicopter altitude during surveys was approximately 100 m Above Ground Level (AGL). In this case, sheep did not habituate or become sensitized to repeated overflights. In Arizona, fixed-wing aircraft overflights during sheep surveys also affected sheep behaviour (750). Low-level overflights interrupted activities and sheep moved >100 m 19% of the time. Responses by sheep varied by altitude: 1) at <50 m AGL all responses were extreme, involving movements of at least 1 km from the area of observation; 2) at 50-100 m AGL responses were mixed, some (13%) extreme, more (27%) mild, and most sheep showed (60%) no overt reaction; and 3) at >100 m AGL responses ranged from mild (23%) to no overt reaction (77%). Helicopter traffic associated with the construction of a well site in southwestern Alberta caused similar levels of disturbance (950811). Responses were observed on 20 occasions (*n*=115 sheep). In most cases (*n*=15, 76 sheep) a significant behavioural response was detected. Reactions ranged from interrupted feeding and slow escape, to panic flight. In 6 instances (*n*=42 sheep), total disruption of activity and herd structure was detected. In 5 observations (*n*=39 sheep), there was no apparent reaction.

Bighorn sheep at Grand Canyon National Park experience heavy helicopter overflight traffic, with estimates ranging from 15,000 to 42,000 flights per year. Time and activity budgets for desert bighorn sheep in the presence and absence of helicopter overflights were examined to determine the extent to which food intake may be impaired by helicopter disturbance (810). The results showed that sheep were most sensitive to the disturbance during winter because they were closest to helicopter flights paths at that time. Sheep sustained a 43% reduction in foraging efficiency during winter. Disturbance distance thresholds of 250-450 m were determined.

Discussion to this point has focused entirely on the overt or behavioural responses to human disturbance. However, the use of heart rate (HR) as an indication of response to disturbance has also been successfully utilized in bighorn sheep. Heart rate is a well-established correlate of anxiety and arousal (i.e., a good indicator of stress) (see 800 for a discussion of heart rate and stress). The effects of human disturbance were examined in detail using heart-rate telemetry in 2 Alberta studies, one at Ram Mountain, (800), and the other at Sheep River (780, 10080). At Ram Mountain the hunted sheep population was captured annually as part of a long-term study. The road which traversed sheep range was used very little. Traffic was usually limited to fewer than 3 trips per day by 1 or 2 trucks used in research and other trucks used the road on <10 occasions during the 3 months of the disturbance project. At Sheep River, the bighorns were hunted outside of a wildlife sanctuary where the disturbance project was conducted. Within the sanctuary, traffic was heavy relative to the Ram Mountain road and sheep were very habituated to humans.

In both studies, responses to disturbance were detected using HR telemetry that were not evident from behavioural cues alone. Of 142 instances when HR response clearly coincided with a disturbance at Sheep River, 73.9% preceded or occurred in the absence of any motor activity by the sheep. Ram Mountain data supported the notion that overt behaviour was a poor indicator of a sheep's stress response to intruders. HR increased sequentially from lying bedded, to standing, feeding, walking, and running. Walking and running produced increases of roughly 25% and 54%, respectively, over bedded HR's (800).

Both studies found that there was a strong relationship between the distance to the road and HR in the absence of vehicles. At Ram Mountain, HR was 15.6% less at 400 m from the road than on it (800). At Sheep River, maximal HR's during bedding, standing, or foraging were recorded from animals proximal to the road. Conversely, vehicles on the roads were not perceived as stressors. At Sheep River, only 19 of 215 (8.8%) documented passes of sheep by vehicles evoked HR responses. Responses occurred only when vehicles were within 200 m of the sheep (780). Of the 19 sheep that evoked HR responses in the presence of vehicles, 73.7% occurred when vehicles passed within 25 m (10080). There was no consistent relationship between vehicle type and HR response.

Both studies documented the effects of helicopters on the HR's of bighorn sheep. At Sheep River, a helicopter refueling site was located about 300 m from a heavily-used part of the sheep range and these sheep would have been exposed to helicopter traffic within 500 m on many occasions. This probably was reflected in the HR responses of sheep there. The appearance on 4 separate occasions of a low-flying Bell 206 helicopter failed to elicit HR responses from ewes 500-1500 m distant. However, during 5 direct overflights by helicopters at 90-250 m AGL, HR's of 3 ewes increased 2-3.5x, with recovery times of 20-65 seconds. These significant increases in HR were likely the result of helicopters "behaving" in ways they normally did not. The relatively quick recovery times are likely a result of some habituation to helicopters in the area.

At Ram Mountain, a fire lookout was located within bighorn sheep range and it was serviced by helicopter. Helicopters were not a novel stimulus for Ram Mountain sheep, although regular overflights were probably more distant from sheep there than at Sheep River. A single, surprise high overpass of a helicopter caused increased HR's in 2 sheep for 27 min., while multiple helicopter overpasses caused elevated HR's for periods of hours. These responses appeared to be more extreme than those recorded at Sheep River and may reflect the different degrees of habituation to helicopters of the 2 sheep populations.

HR responses to transient stimuli usually terminated rapidly, implying that brief disturbances are not particularly costly in terms of energy expended (780). Nevertheless, the 20% rise in mean HR of ewes during continuous exposure to humans indicated that the cumulative effects of these peaks may be energetically significant (780). If sheep do run from a disturbance and the distance moved is great, then HR recovery can be prolonged. At Sheep River, a ewe took 50 min. to recover after running 1.0-1.5 km from an unknown disturbance (780).

Individual disturbance may lead to **social disruption**. Bighorn sheep are a gregarious species. Grouping is thought to reduce the risk of predation. HR data from Ram Mountain indicated that grouping was used to compensate for lack of security; sheep were found in larger groups when they were in insecure habitats (800). Disturbances that tended to break up groups (such as direct overflights by helicopters) disrupted these social groupings, inducing additional stress. Excitement following harassment (as seen by elevated HR's) was significantly shorter when sheep were in larger groups (800). The Sheep River data also implied greater security (i.e., lower HR response to disturbance) with increasing group size (780).

Although bighorn sheep have an ability to habituate to humans in certain circumstances, **habitat avoidance** has also been documented as a result of human activities associated with disturbance corridors and other human developments. A study of the movements of bighorn sheep on the Rocky Mountain Front in Montana demonstrated that heli-seismic exploration could result in temporary range abandonment (950887). In April 1982, 8 bighorn sheep were radiocollared on the Ford Creek winter range. In September-October 1982, prior to disturbance, 71% (10 of 14) of the radiolocations were on the fall-winter range. Three heli-seismic lines were run concurrently across a portion of the fall-winter range of the radiocollared bighorns. During the September-October 1983 seismic activity, no locations occurred on traditional fall-winter range. Instead, 100% (n=17) of the sheep locations were to the south, in part of their summer range. In September-October 1984 (post-disturbance), 45% (5 of 11) of the relocations were again on the fall-winter range. In 1983, average annual home range size declined 28% from 25.9 km^2 in 1982 to 18.6 km^2. Following disturbance in 1984, it increased to 29.7 km^2. A decision to allow a second heli-seismic crew and to amend the operational guidelines to allow lines to run concurrently (as opposed to a 14.4 km spacing requirement) resulted in dramatically increased helicopter activity. This intense helicopter activity was apparently responsible for the dislocation of sheep from the fall-winter range in 1983.

Helicopter activity was also implicated in temporary range abandonment by bighorn sheep in southwest Alberta (950811). In this case, sheep reduced their use of Prairie

Bluff, their traditional winter range, in November 1987 when there were frequent helicopter overflights associated with the construction of 2 gas wells. During that month, there was an average of 9 flights per day onto Prairie Bluff. Sheep re-established their traditional distribution in December, when construction was suspended.

A combination of disturbances including helicopters and ground-based human activities resulted in temporary range abandonment at a new ski development in southwestern Alberta (950809). During 1986/87, the Nakiska ski area was first opened to public skiing and 2 pre-Olympic downhill races were held. Range abandonment occurred on a small portion of the winter range immediately below the "ladies downhill start area". This abandonment was due to human activities on the ridge top, including snow making, helicopter flights, and avalanche blasting (950809).

Disturbances associated with construction of the Hayden-Rhodes Aqueduct (HRA) and new roads associated with the HRA that fragmented or disturbed bighorn sheep habitat caused sheep to temporarily abandon parts of their range in Arizona (18620). However, home range size, use of vegetation associations, and frequency of radiolocations within 500 m of the HRA for bighorn sheep during construction (1980-84) and after completion (1989-92) of the aqueduct did not differ. Its location on the southern edge of deer and sheep range probably contributed to these results because the canal reinforced existing barriers (i.e., highways, agriculture, developments) and did not create a new one.

Ground-based human disturbances may lead to permanent range abandonment in some cases. Desert bighorns in the Pusch Ridge Wilderness (PRW) in Arizona have abandoned 206 km^2 of historic habitat and now occupy 44 km^2 (11900). The PRW is an important recreational area for Tucson. Abandoned sheep habitat is bisected by 2 paved roads and numerous hiking trails traverse abandoned habitat at upper elevations. The results of this study indicated that distance to human development was 2 times greater in habitat currently used by sheep than abandoned habitat. Although the authors felt that distance to disturbance appeared to be a critical factor in sheep habitat use they did not measure the direct effects of disturbance. These results are in contrast to those recorded in California (13790), where range abandonment did not occur. Based on the published accounts, it appears that human disturbance was substantially greater at PRW.

Ewes and rams may exhibit different degrees of avoidance to development corridors and associated human disturbance. In areas where only rams are hunted, it is predictable that rams would be more prone to human disturbance than ewes. However, rams may also show a greater sensitivity to human disturbance in areas that are not hunted (950867). In Idaho, habitat relationships of the Morgan Creek bighorn sheep population were observed in 1989 and 1990. Hunting was closed in the area in 1970 when the sheep population declined to about 70 individuals. Radiotracking 11 rams and 9 ewes in 1988 and 1989 demonstrated that rams used areas further from frequently-used roads than did ewes.

Conversely, in an unhunted population in California, rams appeared to be less susceptible to disturbance than ewes (13790).

Habitat avoidance may also occur if linear developments act as barriers or filters to movement. The Little Harquahala Mountains in Arizona were bisected for the first time by a road leading to a gravel pit in 1981 (950984). Prior to road development, 3 radiocollared ewes were located in the southern portion of the mountain range 24% of the time (38 of 160) between 1980 and 1981. With the development and subsequent heavy use of the road by gravel trucks, only 2 of 188 locations of the 3 ewes were made in that portion of the range south of the road. One ewe never returned, and the other 2 did only once. In 1983, road traffic decreased and sheep occurrence increased slightly, but use of the area through 1985 was sporadic and infrequent (950984). In this case, it appears that the road was a filter to the free movement of those radiocollared ewes. In California, what probably was once one large metapopulation of desert bighorn sheep is fragmented into 5 smaller populations by fenced, multiple-lane highways, and 2 open aqueducts (950877). Aqueducts constructed in the arid southwest United States are barriers to bighorn sheep movements (18620). Since habituation appears to ameliorate the effects of linear developments like roads on bighorn sheep (4680), roads through the ranges of bighorn sheep not accustomed to human disturbance can create filters to bighorn movements.

The direct loss of habitat to linear developments is one source of **habitat disruption** for bighorn sheep. When a road is constructed, grazing land may be removed. However, this loss of habitat in sheep range is generally small. For example, when an access road and 2 gas wells were drilled in bighorn sheep habitat in southwestern Alberta, Morgantini (5040) calculated that habitat loss caused by construction activities affected approximately 11.8 ha (2.7% of potential bighorn sheep range in the study area), comprised of 5.7 ha of alpine tundra (19% of alpine tundra available), 2.8 ha of fescue communities (2.1% of fescue communities available, 1.8 ha of cliff terrain (1.3% of cliff and scree terrain available), and 1.5 ha of unclassified spruce/pine forests (0.8% of forest in the study area).

Direct mortality as a result of linear developments has been frequently documented for bighorn sheep. Direct mortality is usually associated with sheep killed on roads and railways (e.g., 6580, 6670, 11720). Bighorn sheep kills were ranked as "significant" in both Jasper and Banff National Parks in Damas and Smith's (3760) summary of wildlife mortality in transportation corridors through Canada's national parks. In Banff National Park, an average of 11 sheep are lost each year to highway mortality (950811); between 1964 and 1977, 107 bighorn sheep kills were documented on roads and the railway (3850). On the Kootenay Parkway in Kootenay National Park, 27 bighorn sheep were killed by vehicles between 1981 and 1990 (590). The traffic mortality documented in Kootenay National Park represented less than 3% of the population annually (580).

Indirect mortality as a result of development corridors may occur in several ways. First, development corridors provide access for humans into areas that were previously inaccessible. Access leads to increased mortality from legal hunting and poaching (950807). Habituated behaviour resulting from exposure to motor vehicles and human activity predisposes sheep to hunting and poaching (950814). Although these sorts of mortality are often difficult to document, reports of these management problems persist (e.g., in westcentral Alberta [950807]).

Indirect mortality can occur because linear developments and other development-related activities concentrate large numbers of sheep into small areas. Bighorn sheep are attracted to well sites, chemicals, fresh concrete, and other materials associated with oil and gas well sites (e.g., 950811, 950815). Large numbers of bighorns concentrating for a long time in a small area create ideal conditions for the development of contagious ecthyma (9060). For example in 1986, 2 lambs showing the initial stages of contagious ecthyma were found on 2 well sites in westcentral Alberta (950807). One ram, with its face badly scarred by secondary infection, was observed at another well site. Samuel et al. (9060) determined that all infected bighorn herds they examined had prolonged contact with areas where salt was provided artificially. Improved roads that were salted during winter were one of these sources of salt (e.g., highways in Canada's national parks in the Rocky Mountains). Samuel et al. also discovered that most infections in bighorn sheep were found in lambs. Individual sheep with severe cases of contagious ecthyma have difficulty feeding normally often resulting in generally poor body condition. Associated crowding allows contagious ecthyma to spread, as well as spreading of other infectious diseases (950807).

Morgantini and Bruns (950807) summarize additional problems associated with well sites. Palatable grasses are grown on well sites to reduce erosion. These sites could be considered beneficial for bighorns since they may encourage the expansion of bighorn populations into new ranges. However, since these man-made features are often in forested areas, there is a concomitant increase in predation risk, and increased energy expenditures for travel. Cumulatively, these factors may be deleterious to the long-term health of a sheep population. Similar problems exist with all linear developments through forested areas adjacent to bighorn sheep range.

It is very difficult to prove a direct link between disturbance corridors and changes in demographic factors (**population effects**) in a wild sheep population given the numbers of uncontrollable factors that affect sheep productivity and survival. If linear developments are barriers to bighorn sheep movements and sheep populations become small and fragmented, inbreeding will result. Although the deleterious effects of inbreeding have not been unequivocally demonstrated in the wild, a study of captive ungulates did (951034). The study compared juvenile mortality between inbred and non-inbred ungulates of 16 species and inbred juveniles had higher mortality rates in 15 species. Berger (2420) examined how long 122 different-sized populations of bighorns in southwestern U.S.A. persisted over a period of 70 years. His analysis revealed that all populations with fewer than 50 individuals went extinct within 50 years, and that populations with greater than 100 individuals persisted for up to 70 years.

When changes in demographic parameters of a wild population of sheep coincide with human disturbance, without any other implicating factors present, 1 plausible explanation for the changes is cumulative stress associated with human disturbance. This may have occurred at Nakiska, a ski area in southwestern Alberta (950809). For 2 years prior to the 1988 Winter Olympics, data were collected on distribution, productivity, and survival of the bighorn sheep herd. During 1986/87, the ski area was first opened to the public and 2 pre-Olympic downhill races were held. From 1986 to 1987, the population declined 18%. Hunting could account for most of the observed declines in the adult ewes and rams. However, the reason for poor survival of yearlings and lambs was unknown. Survival rates the following year were very high. Had mortality in 1986/87 been stress-related, then that same stress was no longer affecting survival in 1987/88. In this case, sheep may have habituated to the new disturbance.

Similarly there were coincident changes in the productivity for 2 desert bighorn sheep herds that were subjected to human disturbances associated with construction activities near their watering sites. In Arizona, changes in watering practices by bighorns as a result of construction activities were implicated in a very low ewe to lamb ratio (10.5:1) the year following construction activities (3270). The juxtaposition of construction efforts and summer water dependence of bighorn sheep in Nevada caused a significant shift in use of artificial water sources (8970). In this case, productivity during construction did not depart from the long-term population mean; however, lamb survival may have been affected.

7.12 Birds

Published papers regarding the effects of linear developments and human disturbance on birds are numerous. The aim of the following review is to familiarize the reader with the issues regarding birds and human disturbance. Current work is well-represented, but older material is not fully covered. Flight or flush distances refer to the distance between the disturbance and bird when the bird took flight. Flush response is whether a bird flew because of a disturbance.

Individual disruption of birds often involves disturbing individuals at nesting sites, resulting in birds temporarily leaving their nest sites. Virtually all species appear to be susceptible to this type of disturbance. However, there are marked differences among species. Among raptors, bald eagles have been studied most thoroughly. In Minnesota, nesting eagles flushed at a mean distance of 476 m (range 57-991 m) from the approach of a pedestrian (14190). In the Gulkana River basin, Alaska, human activities (boating, camping) disturbed eagles along the river. Breeding adults were less likely to flush and flushed at shorter distances than nonbreeding adults when approached by boats (1850). The distance at which a disturbance was first visible to eagles, the distance they perched from the river, perch height, and eagle age were among the factors that influenced both flush response and flush distance of nonbreeding eagles. In Washington State, flight distances were highest for simulated disturbances on water and on gravel bars, intermediate on land, and shortest under a vegetation canopy (12600). Fixed-wing aircraft passing 20-200 m from nests did not flush incubating or brooding eagles (14190).

Results of studies regarding the sensitivity of eagles at nests *vs*. other areas are conflicting. Bald eagles appeared to be less disturbed by human approaches when away from their nests on the Columbia River estuary, Washington-Oregon (5620). However, in Arizona, bald eagles were more often flushed from perches than nests and were most easily disturbed when foraging (13240). In both cases, pedestrians were the most disturbing stimulus, whereas aircraft was the least. The distance between an eagle and the disturbance was the most important classifier of eagle response. Response frequencies and critical distances for pooled disturbance were 64% at <215 m, 45% between 216 and 583 m, and 24% at > 583 m. (13240).

Other raptors show similar responses to disturbance. In northern Colorado, the flushing responses and flush distances of 6 species of diurnal raptors (American kestrels, merlins, prairie falcons, rough-legged hawks, ferruginous hawks, and golden eagles were measured in winter (15370). Walking disturbances resulted in more flushes than vehicle disturbances for all species except prairie falcons. Although flush distance did not vary with disturbance type for the 3 falcon species, rough-legged hawks and golden eagles flushed at greater distances for walking disturbances and ferruginous hawks flushed at greater distances for vehicle disturbances. Merlins and prairie falcons perched along paved roads had shorter flush distances to walking disturbances than did individuals perched along gravel roads. Rough-legged hawks perched nearer to the road flushed at greater distances than those farther away. For walking disturbances, a linear relationship existed between flight distance and body mass, with lighter species flushing at shorter distances (15370).

In a detailed study of ferruginous hawks (951504), females appeared to tolerate considerable noise close to their nests if they were familiar with it, especially if humans were not visible or otherwise obviously associated with it. Conversely, new forms of disturbance caused desertion if sustained, even though humans were not directly associated with them. In this study, individuals did not habituate to human presence. In fact, most hawks sitting on eggs became sensitized to the human disturbances and flushed at increasing distances until just before their eggs hatched. However, a female usually did not desert after an egg began to hatch or once nestlings were present. The intensity of the response depended largely on whether the disturbance was familiar.

Waterfowl may also flush from nests when disturbed by humans (e.g., blue-winged teal [8660]). However, flushing distances were not reported in the reviewed literature for most species; 1 exception was tundra swans. In the Arctic National Wildlife Refuge (ANWR) Alaska, incubating swans were easily disturbed by ground observers and left their nests when researchers were 500-2,000 m from the nest (18320). Swans did not cover eggs with nest material prior to departure leaving the eggs vulnerable to avian predation and thermal stress. The response of breeding trumpeter swans to human disturbance occurring along the Copper River Highway, near Cordova, Alaska, were similar (6230, 2110). Regular aircraft overflights and passing road traffic alerted birds but did not cause incubating females to leave the nest. Swans were more sensitive to the noise and visible presence of stopped vehicles, pedestrians, and researchers. These disturbances led to frequent recesses by incubating females. Undisturbed swans always covered eggs with nesting material prior to recessing, whereas disturbed females failed to do so on 26 of 28 occasions. Females took longer recesses when disturbed.

The presence of humans, as opposed to human developments, appears to be the most disturbing factor for other bird species also. The degree of reaction to different disturbances is species-specific. Male sharp-tailed grouse demonstrated site tenacity at leks; they remained on leks and displayed despite parked vehicles, propane exploders, taped voices, and a leashed dog (13750). However, they were displaced by human presence. Displaced males remained <400 m away and returned immediately following human departure. Female sharp-tailed grouse seemed less tolerant; they were not observed on any lek during disturbance. Colonial waterbirds exhibited greater than average flush distances in reaction to walking approaches than to motorized approaches (18020, 950195). Double-crested cormorants exposed to human disturbance often became attentive but seldom moved away except when approached by a person on foot (18020). Great blue heron behaviour ranged from relatively minor disturbance in drive-by trials to strong avoidance for approach trials (18020). Pied-billed grebes almost always reacted to human presence, but were particularly sensitive to approach on foot, moving away slowly or fleeing in >95% of the trials (18020).

When birds are disturbed at nest sites, parental care of young may be affected. In Alaska, the behaviour of breeding bald eagles changed when humans camped near (~100 m) versus far (~500 m) from nests (1850). Adults decreased the time they fed nestlings and maintained nests, but increased the time they brooded nestlings. Adults also decreased the frequency with which they fed nestlings (-29%). In Spain, the effects of low-level human disturbance during incubation and nestling phases on marsh harriers were studied (18000). The number of food items delivered and the time spent by males and females in the nesting area and on the nest decreased during disturbed periods, especially during incubation, whereas behaviours related to stress such as alarm calls, chases against other intruding birds, and flying time increased. Nestlings of disturbed birds exhibited levels of blood urea (an index of nutritional level) that were higher than those of undisturbed pairs (18000).

Feeding efficiencies are often affected by human disturbance. When disturbed at nest sites, bald eagles decreased the time they spent feeding (1850). Disturbance of colonial waterbirds in Florida resulted in lost feeding opportunities (18020). Piping plover chicks spent less time feeding (50% versus 91%) and spent more time running (33% versus 2%), fighting with conspecifics (4% versus 0.1%), and standing alert (9% versus 0.1%) when pedestrians or moving vehicles were closer than 100 m than when they were undisturbed (2790). In addition, plover chicks spent less time on the feeding flats (8% versus 97%) and more time in the grass (68% *vs*. 0.1%) during periods of human disturbance. Behavioural investigations of harlequin ducks at Maligne Lake in Jasper National Park revealed that the proportion of time ducks spent diving (feeding) decreased significantly, while time spent flying increased significantly, during midday white-water rafting activities (94383). Similarly, after rafting began, harlequin ducks spent less of their loafing time sleeping and more time just resting as ducks had to remain vigilant to avoid disturbances. Harlequin ducks also showed a significant shift in habitat use within the Maligne Lake outlet once rafting began. The few ducks that remained spent more time near the mouth of the outlet and less time at the preferred foraging areas further downstream (94383). Black ducks curtailed feeding and increased time spent in alert and locomotion behaviours in response to disturbance (11330).

Finally, dispersal patterns of birds can be affected by linear developments. In a study of the dispersal of male willow warblers breeding next to a highway carrying heavy traffic, breeding dispersal was actively directed away from the road (15300). Breeding dispersal distances of yearling males along the road were larger than at further distances from the road. There appeared to be a relationship between dispersal and breeding performance for yearling males, with unsuccessful males moving more frequently and further than successful males (15300).

Not all studies demonstrated that human disturbances were disruptive to birds. In Colorado, boreal owls nested within 30 m of a major highway and there was no evidence that disturbance was an important factor in nest loss or owl movements (951494). In Colorado, vehicular disturbance (0-16 vehicles/15 min) had little impact on nesting burrowing owl behaviour (18090). In a California study, 2 pairs of red-shouldered hawks showed a high degree of adaptability to human-altered habitats and human disturbance (17970). In Alberta, red-tailed and Swainson's hawks have also demonstrated an ability to thrive in human-altered habitats (e.g., 951384).

Many bird species avoid human disturbance (**habitat avoidance**) including those associated with linear developments. Raptor avoidance of human disturbance is particularly well-documented. Goshawks do not appear to tolerate human disturbance and thus may avoid areas of human activity. In a Norwegian study of 21 goshawk nest sites, the distance to the nearest house varied from 250 m to 1,000 m (average 550 m) (15380). Ferruginous hawks seem similar in their inability to tolerate human disturbance (Alberta [951384], Montana [951504]). In the Montana study, only 52% of territories containing disturbed nests (*n*=24) were occupied the year after disturbance; in contrast 93% of the territories containing control nests (*n*=38) in 1978 were occupied in 1979 (951504). In Alberta, only 1 of 37 nests of ferruginous hawks was located within 500 m of an occupied farmyard (951384). Swainson's hawks, on the other hand, appear to tolerate humans in close proximity. In the same Alberta study, 15 of 68 Swainson's hawk nests were located within 500 m of a human residence (951384). Cooper's hawks also seem to need less privacy. Habitat attributes of 21 Cooper's hawk nests in an extensively-forested region of the northeastern United States were studied (15430). Nest sites were not significantly further from paved roads than were random sites. Five nests were located within 37-100 m of paved roads suggesting that nesting Cooper's hawks can be remarkably tolerant of car traffic. However, most nests occurred in deeper forests since distance to paved roads and human habitation averaged 511 m and 687 m, respectively. Most nest sites in another study from the same region were in habitats comprised largely of forest (73.3-99.1%) with very little suburban habitat (0-6.7%) (17830).

In Washington State, human activity adversely affected bald eagle distribution (12600). Distribution patterns were significantly changed, resulting in displacement of eagles to areas of lower human activity. Older birds were more sensitive. On Chesapeake Bay, shoreline segments used by bald eagles had more suitable perch trees and a larger percentage of forest cover than unused segments (18490). Developed shoreline segments had fewer suitable perch trees and less forest cover than did undeveloped forested segments. Most wintering roosts at Chesapeake Bay (86%) were in woodlots >40 ha, and none were in human-developed areas (13080). In contrast, only 23% of random sites were in woodlots >40 ha, and 9% were in developed areas. Roosts were farther from human development than were random sites (13080).

Bald eagle nests sites were often located to minimize human disturbance. In the Chippewa National Forest of north-central Minnesota, nests were farther from houses than were random shoreline points (14190). Recently-used nests in mixed-conifer forests in Oregon had fewer recreational facilities and roads in proximity than old unused nests in the same territory, suggesting a shift from human activities (10890). Modeling of bald eagle nest sites in Maine revealed that bald eagle nests were negatively associated with area of land disturbed by humans compared to random sites (12880). The length of roads near nests was also a negative variable. Similarly, in a study from northern Spain, 3 pairs of golden eagles selected the most inaccessible cliffs (high and far from tracks, roads, and villages) for nesting (15560).

Preferred foraging sites were also avoided by bald eagles if they were disturbed by humans. The response of breeding bald eagles to human activities in foraging areas on the Columbia River estuary, Washington-Oregon, showed that boating activities had the potential to significantly affect eagle spatial use patterns (5620). Eagles typically avoided an area within 400 m of an experimental stationary boat, although avoidance areas ranged between 200-900 m among pairs. In most cases, eagles spent less time and made fewer foraging attempts in the disturbance area. Responses were consistent among nesting stages (incubation, nestling, post-fledging). Bald eagles fed extensively on sheep carcasses in the Willamette Valley, Oregon during winter (14530). Bald eagle use of carcasses was affected by their location; those <200 m from a road or house were rarely used by eagles and persisted longer than carcasses farther away.

Avoidance of human developments has also been demonstrated for a variety of waterfowl species. The presence of Canada goose broods in many metropolitan parks, indicates that goose broods can tolerate of human disturbance (11680). However, in southcentral Washington, broods avoided areas of human habitation in their home ranges, particularly during the first few weeks after hatching when broods appeared most sensitive to human disturbance (11680). In England, pink-footed geese avoided human disturbances while foraging in fields (951424). The use of particular fields and the location a flock first landed in a field were directly related to the number of vehicles that used adjacent roads. Fields next to heavily-used roads were used significantly less than roads with little traffic. Human disturbance caused wintering diving ducks on the Mississippi River to congregate in less-disturbed areas (3120). Ninety percent of the waterfowl present in the study area were found in 28% of the study area during the daytime. Harlequin ducks also avoid areas frequented by humans (e.g., 630, 94333, 94343).

Passerines are also affected by human disturbances and the avoidance of disturbance corridors like roads have been well-documented. For example, a breeding bird study in woodlands in the Netherlands showed that of 43 species, 26 (60%) showed evidence of reduced density adjacent to roads (14670). Similar results have been reported for grassland habitats (e.g., 951394, 951404, 951414). In general, when an disturbance corridor is cut through a forested area, interior-forest dwelling birds avoid the corridor and forested habitats along its edge. Birds that are considered habitat generalists become more common along the corridor (e.g., 14160, 13330, 4830, 1250, 6800, 2260). In a Michigan study on the effects of size and shape of forest disturbances on the densities and spatial distributions of 3 forest-dwelling songbirds, the amount of disturbance was related to opening size (4170). A petroleum pipeline-corridor represented a narrow rectangular (15 m-wide) opening. Declines in red-eyed vireos were more severe for large openings than medium ones, and were detected over greater distances into the forest interior.

Average reductions in densities of 22-50% were detected over distances of 250 m and 400 m for medium and large openings, respectively. No avoidance was observed for small or narrow-rectangular openings . Declines in breeding density of ovenbirds were not observed. Least flycatchers were displaced farther into the forest interior as size of openings increased. If bird surveys are conducted shortly after a disturbance corridor has been created, increased densities of forest-dwelling birds may occur in forest along the corridor (94513). The increase in density within the forest stand adjacent to the corridor occurred because displaced individuals packed into remaining the habitat. The duration and extent of increased densities following cutting of a corridor depended on many factors, including the sensitivity of a species to edge and area effects, the duration and rate of habitat loss and fragmentation, and the proximity of a forest stand to the disturbance (94513).

Traffic volume affects the degree to which birds avoid roads. In a detailed study from the Netherlands, calculated 'effect distances' (the distance from the road to where a reduced density was observed) varied between species from 40-1,500 m for a road with 10,000 cars per day to 70-2,800 m for a road with 60,000 cars per day (vehicle speeds of 120 km/hr and woodland accounting for 70% of roadside habitat)(14670). Noise, but not visibility, was considered the most important factor effecting changes in densities along roads (14670). Similar effects were discovered for grassland habitats. Again from the Netherlands, disturbance distances varied between species, ranging from 20 to 1,700 m from the road at 5,000 cars per day, and from 65 to 3,530 m at 50,000 cars per day (951394). At 5,000 cars per day, most species had an estimated population loss of 12-56% within 100 m of roads. At 50,000 cars per day all species had estimated losses of 12- 52% up to 500 m.

Disturbance corridors passing through forested areas result in fragmentation; large contiguous blocks of forested habitat are broken up into smaller blocks. The effects of forest fragmentation as a result of the linear developments can result in declines in species numbers and abundance within the remnant forests. In France the abundance of 6 forest breeding species was negatively correlated with the degree of forest fragmentation (11400). Remnant area was a significant predictor of the total number of bird species and the number of raptors occurring in 9 remnant forests in Australia (17130). As was the case with individual disturbance corridors, responses to fragmentation and remnant area are species-specific. Of 16 birds species censused in a managed forest in southeastern Wyoming, brown creepers and hermit thrushes were the most negatively influenced by fragmentation; pine siskins were the most positively influenced by fragmentation (11840). In England, species which were largely dependent on woodlands and that seldom occurred in other habitats required woods of ≥10 ha to breed successfully (94483). Similarly, in remnant corridors of riparian vegetation, corridor width affected the species composition and abundance of birds (18540). Forest-dwelling species (e.g., golden-crowned kinglet, Swainson's thrush, blackpoll warbler, and black-throated green warbler) were less abundant than ubiquitous species in 20-m wide remnant corridors. There was evidence that 60-m wide strips were required for forest-dwelling birds. The northern spotted owl is a well-studied example of an old growth forest-dependent raptor that is negatively affected by fragmentation (11040, 4960, 17810, 16550).

Lack of avoidance of linear corridors such as roads has also been documented. In landscapes where surrounding habitats have become severely altered by human developments like agriculture, bird species are attracted to the remnant grassland corridors associated with roads (15250). In central Iowa, 35 bird species were seen in roadsides, compared with 26 species in rowcrop fields (15510). In an agricultural landscape in Iowa, ring-necked pheasant nest densities on seeded roadsides exceeded all other cover types (13510). Gray partridge in eastern South Dakota used roadsides in late spring for nesting (10420). Road rights-of-way are also increasingly valuable prairie duck nesting habitat (e.g., 9480). In Nebraska, 62 % of 206 duck nests were located on roadsides and alfalfa (8090). Road rights-of-way are also used frequently by blue-winged teal (e.g., 5410, 14760).

Direct loss of habitat for birds, or **habitat disruption,** as a result of linear developments tends to be a small percentage of an area. For example, in an area of oil and gas exploration in northwestern Alberta, there were 2.08 km of linear development per km^2 (950787). Those linear developments accounted for approximately 13,900 ha of wildlife habitat or 2% of the study area. The Prudhoe Bay Oilfield occupies about 500 km^2 and in 1983 there were more than 350 km of roads (951274). Less than 5% (21 km^2) of the tundra was covered with gravel. Another 2.8% (14 km^2) was flooded because of road and gravel construction (951274). Again, the effects of these losses are probably minor compared with losses caused by avoidance and mortality.

Habitat enhancement as a result of linear developments like roads has been documented for many bird species. Although many forest-dependent species are often negatively affected by linear developments and fragmentation, other bird species, particularly mixed-habitat and early successional species, increase in numbers along these linear features (17270, 4830). Grassland species generally prefer right-of-way habitat and many less habitat-specific species are often distributed in rights-of-way and adjacent habitat (1250). Fragmentation often results in increases in the number of bird species, species diversity, and abundance in the vicinity of edges at the expense of interior, forest-dwelling species (e.g., 2780). Corridor width and habitat within the corridor may also affect species composition and abundance (12820).

Large transmission line towers in open landscapes are often used by birds for nesting. In one region of eastern Germany, transmission line pylons comprised 50% of all nest sites (16040). In southern Idaho and Oregon, raptors and ravens began nesting on towers along a 596-km segment of a 500 kV transmission line within 1 year of its construction

(18120). Rapid colonization of towers along the line probably was due to lack of other nesting sites in the transmission line corridor, and the proximity of existing nesting populations in the nearby Snake River Canyon. Transmission towers provided both new and alternative nesting sites and nesting success of pairs on transmission towers was similar to or higher than that of pairs nesting on other sites (18120). Similarly, in the Mojave Desert of California, red-tailed hawks and their nests were more abundant along powerlines than along control transects (15680). The data suggested that hawks were more common along powerlines because of the presence of superior perch and nest sites. Raised pipelines in the Arctic have been used in a similar fashion by gyrfalcons (951444). The use of other man-made structures by cliff nesting raptors is well-known. Peregrine falcons raise young in many North American cities, including Calgary and Edmonton, Alberta. Rough-legged hawks in the Arctic have also been documented nesting on unoccupied camp buildings within 400 m of the Dalton Highway (951444).

Seismic lines may also enhance habitat for ptarmigan by promoting the growth of willows (94463). Ptarmigan appeared to be indifferent to the seismic lines unless there were exposed willows on the lines; in such cases the birds did not hesitate to feed on the lines.

Direct mortality to birds as a result of linear developments occurs as a result of vehicle collisions on roads and collisions with and electrocutions on electrical transmission lines. All bird species whose habitat is bisected by roads suffer from collisions with vehicles (e.g., 70, 15190, 14340, 4990, 7300, 15470), and birds attracted to roadsides like meadowlarks, and red-winged and Brewer's blackbirds are killed in the greatest numbers (1250). Along the TransCanada Highway in British Columbia, pine siskins are attracted to the road in winter by the thousands and hundreds may be killed by a single vehicle (18890).

Owls appear to be very susceptible to collisions with vehicles probably because of their nocturnal habits and, in the case of certain species, their attraction to open areas for hunting. During a 10-year study in southern New Jersey, 250 road-killed raptors of 6 owl and 6 hawk species were found during 145 km of road travel between mid-October and early April. Northern saw-whet owls and eastern screech owls accounted for 45% (n=114) and 36% (n= 91) of all road kills, respectively. A large percentage of the saw-whet (79%) and screech owls (88%) found were less than 1 year old (15470). Similarly in Europe, 51% of the barn owls reported dead had been victims of road traffic, and 82.2% died during their first year of life (14480). In a study of barn owl mortality along two California highways, differences in the adjacent habitat appeared to be responsible for the distribution of fatalities among the 3 sites (18930). Again, young birds were killed most frequently. However, in this study there was also a significantly skewed sex ratio: 74% of the collected owls were females. In Germany, traffic speed, not traffic flow, was the major factor in traffic-caused fatalities of owls (951374).

Ducks are also killed frequently along roads (e.g., 9480). In a road mortality study in prairie habitats of North and South Dakota, 562 adult ducks of 11 species were found (9480). Dabbling ducks were more vulnerable than diving ducks because dabbling ducks made greater use of seasonal wetlands along roads and uplands for feeding and nesting. Dabbling duck hens were more vulnerable than drakes and most mortality occurred during peak nesting months (May and June). Duck vulnerability varied by type of road; 87% of dead ducks were found along surfaced roads while just 17% were found along unsurfaced roads. Differences in traffic volume and speed of traffic affected the number of ducks killed on roads. Average annual mortality ranged from 0.156 ducks per km for an interstate highway (7,600 vehicles/day) to 0.005 ducks/km on unsurfaced roads (72 vehicles/day). Relative to the amount of traffic, ducks were most vulnerable on narrow highways bordering wetlands.

Electrocutions and collisions with transmission lines are a source of mortality for many bird species (870). A recent review of the literature showed that 15 orders, 41 families, 129 genera, and 245 species were recorded among the victims (16070). Waterfowl and cranes are often affected where transmission lines cross water and other open landscapes (18450, 6540, 990). Birds are killed most frequently during migration in the spring and fall (16200, 18450). Studies from Norway have identified that several tetraonids (grouse) are also frequent victims of powerline collisions in boreal forest habitats (16000, 15960). Bevanger (16140) reviewed the causes of collision and electrocution accidents involving birds and power lines. The review grouped causes according to biological, topographical, meteorological, and technical aspects. The important biological variables were connected with morphology, in particular body size, aerodynamic capability, physiology, behaviour, and life-history strategies of different bird species. For example, birds with larger wing spans are more susceptible to electrocutions than smaller birds. This can lead to sex-biased mortality in bird species like raptors where females are larger than males (e.g., 8050). Meteorological influences included wind speed. Increased wind speeds increased the frequency of collisions in Colorado (18450). In a study of waterfowl mortality related to high-voltage transmission lines at a power plant in Illinois, factors contributing to frequency of collisions were the number of waterfowl present, weather conditions and visibility, species composition or behaviour of birds, human disturbance, and familiarity of birds with the area (6540).

Indirect mortality as a result of human disturbance and linear developments may be more important to bird populations than direct mortality. Nest desertion is a common problem when birds nest in areas exposed to human disturbance like linear developments. In a population of piping plovers subject to variable degrees of human disturbance on their breeding grounds, nest site desertion was higher for plovers breeding in areas of high human disturbance (2790). Disturbance ranged from occasional pedestrian activity to intensive off-road motor vehicle traffic. Fifty-two black duck nests (9%) were abandoned as a direct result of disturbance by humans in a 10-year study of the reproductive success of that species in the St. Lawrence River estuary (8260). The impacts on ferruginous hawks of treatments designed to simulate those encountered during geothermal development were assessed in Idaho (880). Seven of 23 nests exposed to simulated disturbance were deserted over 2 breeding seasons. In a similar study in Montana, 24 ferruginous hawk nests were disturbed and 33% of disturbed nests were deserted by the adults, although human presence in the vicinity of the nest was brief (951504). In Scotland, golden eagle nests more accessible to people failed more frequently than those in inaccessible sites (15880), although the actual causes of failure were not known.

Increased predation at nest sites in the vicinity of linear developments was often identified as an important source of mortality for local and regional forest-dwelling bird populations (an "edge effect"). Increased predation is caused by increased access to nests by predators. This can occur in a direct manner when birds are disturbed from nests leaving eggs or nestlings unguarded (e.g., piping plover [2790], eider duck [951354]). Increased predation can also result if linear developments allow predators access into areas they did not previously travel (9620, 13900, 15100, 17610). Remnant grassland corridors along roadsides used by nesting birds may suffer high predation rates because predators can hunt these corridors more efficiently. In central Iowa, 55% of red-wing nests and 52% of the nests of all species along roadsides were destroyed by predation (15250).

Increased fragmentation of continuous habitats, often as a result of the construction of linear developments, may also result in increased predation by a variety of nest predators (17430, 16910, 16290, 18210, 17270, 15100). In a breeding duck survey in grassland habitat, variation in duck productivity among blocks was associated with block size and presence of predators (18430). Average productivity of dabbling ducks on large grassland tracts with relatively low predator populations was several times higher than in many parts of the prairie pothole region where the effects of habitat fragmentation and high predator populations supported by humans were severe. Similarly, in fragments of tall-grass prairie in Minnesota, rates of nest predation for 5 species were lower for nests on large fragments, and in areas farther from a wooded edge (12390). In deciduous forest fragments, predation rates along a forest/farmland edge were higher closer to the edge than further inside the wood (12590). Not all studies have demonstrated a relationship between fragmentation and predation (e.g., 17740, 9620, 18110, 18270, 14380), and additional research, particularly on the changes in predator community dynamics as a result of habitat fragmentation, has been called for (18110, 17430, 94523).

The rate of parasitism by brown-headed cowbirds on bird nests is also affected by disturbance corridors and fragmentation (17270, 17430, 17720, 15100, 16910, 16290). Generally, there is a decrease in the relative abundance of cowbirds as the distance from the forest increases (e.g., 17720). In a study of 3 types of ubiquitous, narrow, forest-dividing corridors, cowbirds were more abundant than 20 of 21 forest-interior neotropical migrants (13900). Corridor widths as narrow as 8 m produced forest fragmentation effects by attracting cowbirds to corridors and adjacent forest interiors. Among wood thrushes nesting in fragmented habitat in central and southern Illinois, 89-100% of nests contained cowbird eggs (15100). In fragments of tallgrass prairies in Minnesota, rates of brood parasitism on 5 bird species were affected by the size of the prairie fragment containing the nest and the distance from the nest to a wooded edge. Rates of brood parasitism were lower far from a wooded edge (12390).

Linear developments also provide access for human predators. In a study of ruffed grouse near Rochester, Alberta, hunting along roads accounted for 96% of shot birds (6450). Loss of territorial adult male grouse to hunters decreased significantly with increasing distance from banding location to the nearest road: 48, 13, 5, and 1% of those banded < 101, 101-200, 201-301, and ≥302 m, respectively, from the nearest road and surviving to 1 October were reported shot. Similarly, in Alaska, hunting along roads in autumn removed about 13% of grouse that had been banded within 2 miles (3.2 km) of roads in summer or early fall (5970). Intuitively, marshes and other water bodies will probably not be used by fall waterfowl hunters if they cannot be reached along a disturbance corridor (e.g., road, trail) .

Not all studies concluded that human disturbance resulted in increased mortality, direct or indirect. Red-tailed hawks in an urban/suburban landscape around Syracuse, New York were not affected by human disturbance (2230). For 16 nest sites with records longer than 4 years, mean productivity was not significantly related to the distance to the nearest road. In Colorado, vehicular disturbance (0-16 vehicles/15 min) had no impact on productivity of burrowing owls even though nesting locations placed them in close proximity (18090). In a bald eagle study from Minnesota, researchers found no evidence that human activities had an important impact on reproductive success on the Chippewa National Forest (14190). Unsuccessful nests had no greater frequency of known human activity within 500 m than successful nests. In another bald eagle study, this one from Oregon, human disturbance accounted for 2% of nest failures, while pesticides and proximity to nearest-neighbor breeding pairs accounted for 32% and 11%, respectively (18170).

Population effects have been documented for regional and local bird populations as a result of disturbance associated with linear developments. Probably the most important population effect that has been documented is associated with fragmentation that linear developments cause on otherwise contiguous landscapes. Abundances and reproductive rates of forest-dwelling birds are often depressed (5370, 16290, 17730). In 9 midwestern (U.S.A.) landscapes where forest cover varied from 6 to 95%, observed reproductive rates were low enough for some species in the most fragmented landscapes to suggest that their populations were sinks that depended on immigration from reproductive source populations in landscapes with more extensive forest cover for perpetuation (16910). Similar results were obtained in a study of the effects of fragmentation on red-eyed vireo, ovenbird, and wood thrush populations in the midwest U.S.A. (16290). Based on field data, ovenbird and red-eyed vireo populations would become extinct in fragmented landscapes and wood thrush populations would be maintained or slightly decline without immigration. Conversely, populations of all 3 species would increase on contiguous forest tracts without emigration. At a landscape scale, the consequences of apparently small reductions in forest area by the presence of narrow forest-dividing disturbance corridors (as narrow as 8 m) may be cumulatively significant for abundances of forest-interior species (13900).

A study of the history of breeding bird species on 14 European islands showed the effects of small population size on population survival (17580). Most small populations disappeared quickly, but a few lasted a long time. Population lifetimes (colonization to extinction) were calculated to be 1-5 years for hawk, owl, and crow populations when there were just 1-2 breeding pairs. Lifetimes rose by a factor of 3-4 for each additional pair up to 3 pairs and rose more slowly thereafter. The authors suggested that lifetimes of some northern spotted owls populations in the smallest forest fragments will be short unless active management is implemented (17580).

Species composition has also been related to forest fragmentation. Smaller habitat fragments have fewer bird species that are dependent on that habitat for survival (9640, 2080, 17130). In the midwest U.S.A. many migrant songbirds are absent from all but the largest woodlots (15100). In California, the area of chaparral habitat and canyon age (time since isolation of the habitat fragment) explained most of the variation in the number of chaparral-requiring bird species found in 37 isolated fragments of canyon habitat (4600). Smaller chaparral fragments had fewer chaparral-requiring species. Differential extinction of forest species following forest fragmentation was also studied in an 86-hectare woodland in west Java (2080). The 2 main variables that identified extinction-prone bird species in the woodland were small initial population size in the woodland and rareness or absence in the surrounding countryside. Although the woodland retained wooded habitat, it was evidently too small to retain self-sustaining populations of many woodland bird species. Small populations at high risk of extinction for stochastic reasons (e.g., unpredictable environmental factors like bad weather) were doomed to disappear permanently unless subsidized by recolonization from the surrounding areas (2080).

Human disturbance has been implicated in population declines of some bird species. In Jasper National Park, Alberta, an 80-90% decline in harlequin ducks on the Maligne River over a 6-year period was positively correlated to the total number of boaters using the river (630). Factors affecting status and reproduction of ospreys in Yellowstone National Park were studied during 1972-77 (13610). The population declined from an estimated 120 breeding pairs in 1917 to 100 adults (about 45 pairs) in 1974. Reproduction was higher along streams with little human disturbance than on Yellowstone Lake which received more human use. Reproduction in undisturbed nests was apparently sufficient to maintain an osprey population, whereas reproduction in disturbed nests was not. Electrocutions and collisions with powerlines affect the viability of populations of the endangered Spanish imperial eagle in Spain (8050). In a Netherlands study, road kills were sufficient to cause a population decline in barn owls (14880). This study area proved to be a sink where the barn owl population persisted through immigration.

Conversely, although many ducks were killed along roads in a study area in North and South Dakota, the high value of road rights-of-way as prairie duck nesting habitat was not significantly reduced by vehicle-caused mortality (9480).

8.0 Mitigating Measures

A wide variety of techniques exists to mitigate the effects of linear developments on wildlife. Most mitigation measures carry a price tag; in some cases the cost can be substantial (e.g., 18900). This cost -- often considered "additional" in the eyes of decision-makers -- has been used as a reason not to include mitigation measures as part of a development project (e.g., 6310). However, if an objective of the project is the reduction of disturbance effects on wildlife, then these costs should be viewed as an integral part of disturbance corridor construction and maintenance. The economics of development should take in account the costs of maintaining functioning, intact ecosystems with self-sustaining wildlife populations.

Mitigation techniques vary in their usefulness depending on a wide variety of factors including the target wildlife species, geographic location, and disturbance corridor type. Unfortunately, the efficacy of many of these techniques has not been rigorously examined even in areas where they have been in use for extended periods (650). There is an urgent need to conduct these kinds of assessments (e.g., 650, 16140).

8.1 Regional Planning

Since development and disturbance corridors have their greatest effects at the landscape level (e.g., 80), it is appropriate that the most effective measures to mitigate the effects of these corridors should occur at the same scale. In addition, many species that are sensitive to disturbance have land requirements that must be viewed at this scale (e.g., grizzly bears, wolverines). Planning development corridors at the regional or landscape scale provides the greatest opportunities for mitigating the effects of these disturbance corridors on these species. McLellan (86, 2240) felt that management and planning for wide-ranging species like the grizzly bear should focus habitat management and planning in areas that are gradually being settled. These areas that lie between relatively wild habitats are very important to conservation today since they are currently under the most human pressure. Regional habitat fragmentation will occur if these areas are lost; wilderness areas will become islands, and wildlife in them will be isolated. Isolation of populations is viewed as a serious threat to the long-term persistence of wide-ranging mammalian species in many areas (86). Apps (951684) and Gibeau et al. (950707) are using this approach in their assessments of grizzly bear habitats in the Rocky Mountains.

There are several examples of regional research and planning groups in existence or proposed in Alberta. Caribou have provided the focus for 2 such groups, the North East Regional Standing Committee on Woodland Caribou (NERSC) was formed in 1991 with a mandate to discuss and support research on caribou conservation and industrial development (950557). There are over 30 companies and government divisions involved. The goal of NERSC is to develop a knowledge-based management plan for woodland caribou in northeastern Alberta. The area is under pressure from many different human activities such as oil and gas development, forest harvest, agriculture, and recreation, and linear developments have proliferated. A group with a similar emphasis on woodland caribou, planning processes, and coordination of development activities has formed in northwestern Alberta (951704). Herrero and Herrero (80) recommended a management advisory board involving various regional, provincial, and federal stakeholders to oversee regional-level carnivore research and planning in the westcentral Rockies where Cardinal River Coals Ltd. has recently proposed to develop coal reserves. West of Calgary, the Banff-Bow Valley Task Force's objectives were to develop a vision and goals for the Banff-Bow Valley that would integrate ecological, social, and economic values, to complete a comprehensive analysis of existing information, and to provide direction on the management of human use and development in a manner that will maintain ecological values and provide sustainable tourism (951734). The development of a strategy that will ensure the conservation of large carnivores in the Rocky Mountains has been the goal of an international multi-stakeholder group in a process initiated by WWF Canada in 1979 (250). There are many other examples across Canada and in the international arena. These initiatives have in common a regional research and planning perspective that takes into account all the developments that are occurring or that may occur in the future. Only at this level can the cumulative effects of development in general, and development corridors in particular, be adequately addressed. This inclusive, multi-stakeholder approach avoids piece-meal efforts and mitigation that have occurred in the past when individual companies assessed the impact of their operations in the immediate locale they were working without regard for broader-scale effects at the landscape level, and other developments within the region they were operating.

Most landscapes and regions are affected by development and development corridors to some degree and in many cases disturbance to wildlife occurs as a result of many different factors. Given that the detrimental effects of disturbance may accrue in wildlife populations without generating obvious population responses (e.g., precipitous declines), regional planning in the future may require that different interests use regions or landscapes in a staggered fashion. By reducing the levels of human use in a landscape over a given period, the deleterious cumulative effects of several disturbance activities occurring at the same time can be avoided. This staggering of use should include public access. Public access for recreational purposes, particularly hunting, probably results in the most detrimental disturbance effects of development corridors.

Cumulative effects assessment (CEA) in combination with geographic information systems (GIS) technology has been used as a powerful tool in assessing the impacts of linear developments on wildlife (e.g., 4270, 950707, 280, 80). The development of CEA techniques and the use of GIS for analysis is an area of on-going research. Several new techniques are currently being developed. One such technique is a linkage zone prediction model used by Servheen and Sandstrom (18820), Apps (951684), and Gibeau et al. (950707) to assess the degree of habitat fragmentation caused by the cumulative impacts of various human actions along development corridors. These linkage zones can be spatially identified on detailed maps so that management emphasis can address future human actions in these areas. Managers can implement land management activities and public education to minimize future habitat fragmentation or enhance linkages between areas that are being fragmented by development corridors.

Once planning at the regional or landscape scale has identified the kinds of disturbance effects that may occur as a result of linear development, then specific remedial actions can be planned. The first and foremost way to avoid the disturbance effects of development corridors is to minimize the number of corridors that are constructed. The necessity of each and every disturbance corridor in a planned development should be reviewed as to its purpose, necessity, and redundancy. There are many examples of ways that the number of disturbance corridors into an area can be reduced through thoughtful planning and cooperation within and between different resource sectors. Many of these options are currently being used in northern Alberta by development interests (e.g., 950557). Where possible, corridors should be amalgamated to reduce the fragmentation effect of many small corridors. Rights-of-way can be designed to serve dual functions as road and pipeline corridors. When more than 1 operator is working in a area, access should be shared. Any reductions in the number of development corridors in an area will be beneficial to wildlife since additional disturbance effects are avoided.

Open road densities are a useful measure of the ecological effects of roads on a landscape (18880). Road density thresholds -- the density of roads above which a species no longer occurs in an area -- have been determined for wolves in the northcentral U.S.; wolves rarely occupy areas with road densities greater than 0.6 km/km^2 (e.g., 9670, 6830). Allowable road densities in grizzly bear recovery zones in the U.S. range from 0.47 km open road/km^2 to 0.62 km/km^2 (18760). In areas where the conservation of these species is an objective, open road densities should be maintained below these thresholds.

8.2 Corridor Attributes and Location

External and internal attributes of disturbance corridors can be altered to reduce their filter or barrier effect. Whenever possible, corridor width should be minimized. Hand-cut seismic lines are preferred to 8-m wide conventional lines. Curvilinearity should be increased where possible. For example, doglegs in pipelines to reduce lines of sight should be incorporated. Roads should be developed and maintained to the minimum standard necessary for their stated purpose. Low road standards deter use, and promote lower vehicle speeds and reduce the likelihood of collisions. Along natural wildlife movement corridors such as drainages and ridge lines, shrub growth should be promoted to the edges of the road. Most changes that promote increases in connectivity between habitats on either side of disturbance corridors carry costs, often involving increased operating expenses and time, and, in the case of roads, reduced travel speed and safety. However, if the objective is to reduce the impact of linear developments on wildlife, traveling slower and with increased vigilance should be a cost that is acceptable.

The effects of disturbance corridors can be substantially reduced by routing them to avoid areas where disturbance may be greater or unacceptable. Prior knowledge of wildlife use in a landscape is necessary to plan the alignment of a development corridor to minimize the effects of disturbance. For example, elk and deer migration routes are often areas where disturbance corridors have a significant impact because of high collision rates in these areas (e.g., 8810, 5860). Similarly, roads through moose winter range are frequently high road kill areas for moose (e.g., 4800). Transmission corridors that cross water or other open landscapes affect migrating cranes and waterfowl (18450, 6540). In the case of transmission lines, the route planning process should include mapping of topographical features which represent flight lanes for migrating birds and/or are important for local movements of resident species, and key areas for birds (16140). If disturbance corridors are routed to avoid these areas, disturbance impacts can be reduced.

Avoidance of habitat in the vicinity of roads is well-documented for virtually all species of wildlife. The degree of avoidance varies greatly depending on the species, habitat attributes, and prior disturbance history. When roads or other disturbance corridors open to public travel are routed around specific wildlife habitat to reduce the corridor's impact on a particular species, the chosen route should take into account the typical avoidance buffers documented for that species. For example, riparian areas are generally high-quality habitat for grizzly bears (e.g., 18820, 951774) and avoidance of open roads by non-habituated grizzly bears has been documented to more than 500 m in all seasons (e.g., 950097). Access roads in grizzly bear country should be routed to avoid important riparian areas by at least 500 m.

8.3 Access Management

In many ways, development corridors per se are not the most significant factor in determining the degree of disturbance that occurs in the vicinity of a corridor. Human activity associated with development corridors is the primary source of disturbance for wildlife. For this reason, probably the most powerful tool available to reduce the effects of disturbance corridors on wildlife is access management, the control of human use of the development corridor (e.g., 18760). NERSC has recognized this fact and has developed an access management plan for key caribou areas (950557). Their plan includes the creation of low-quality access to discourage other human use, narrower seismic lines (4 m versus 8 m conventional lines), reclamation of old and temporary access roads including rolling slash back onto the roads and the removal of bridges and culverts, manned and unmanned gates at access points, and education both externally with the traveling public and internally with field staff. Similar access management plans are in place in northwestern Alberta to protect caribou (950747, 951704), and the forest industry also recognizes the importance of access management (e.g., 950337).

Community support is necessary. All resource users need to accept the basic tenet that disturbance corridors are detrimental to wildlife and increased human use of these corridors increases the number and severity of detrimental effects. This support is often difficult to obtain from recreational users who feel they have a right to use new access roads developed on public land. For example, the Alberta Pacific Forest Management Task Force could not reach consensus on the need for a no-hunting corridor along access roads constructed by Alberta Pacific Industries in its Forest Management Area in northeastern Alberta (951714), even though the results of hunting along roads are among the best-documented effects of disturbance corridors. Strategies the task force agreed to included some that would increase the impact of the disturbance corridor on wildlife. For example, trapping activities were not to be affected and closing roads or limiting access was only to be considered when the implementation of other options was not feasible or had been unsuccessful (951714). According to the task force, the predominant reason for access management was to prevent over-hunting within the Forest Management Area and there was no mention of other issues regarding roads such as habitat avoidance and indirect mortality.

Other possibilities to reduce the impacts of development corridors through access management include planning activities requiring access to periods of the year when disturbance may be reduced for particularly vulnerable species (e.g., winter development activity preferred in bear habitat, except that areas known to be important for denning should be avoided during winter). Use of roads should be restricted to essential trips and where possible, vehicles should travel in convoy and should stop only when necessary.

8.4 Fencing

Fencing can be an effective tool to reduce direct mortality of wildlife on roads as a result of collisions with vehicles and has been in use for over 60 years (9510). However, fences are also barriers to wildlife movement, and additional measures are required to maintain habitat connectivity on either side of the fenced road (see 8.5 below). European researchers recommend the use of a combination of fencing and wildlife passages for roads and railroads that combine high traffic volume with high speed, to reduce the risk of ungulate traffic collisions (18860). Examples of fencing to reduce wildlife collisions in Canada are the TransCanada Highway in Banff National Park (18900) and the Okanagan Connector Freeway in British Columbia (820). Fencing is generally not recommended on other low speed and low traffic volume roads.

The type of fencing used depends on the species the fence is intended to exclude from the roadway. Fences have been used most frequently to keep ungulates off roads. Elk, deer, and moose were the target species in many cases (e.g., 12060, 670, 5210, 140). Barbed wire fences have not been as effective as woven or page wire fences for ungulates (140, 6820, 12060). Ungulate fencing ≥2.4 m has been used effectively throughout deer and elk range in the western U.S. and western Canada (140, 4900). In Banff National Park, 2.4 m page wire fencing reduced ungulate collisions on the twinned TransCanada Highway by 94-97% (12060). In 1 study in the eastern U.S., a 2.2 m high fence was found to be less effective than a 2.7 m fence in reducing the number of white-tailed deer on the highway right-of-way (5000). Data on deer crossings prior to installation of a fence can indicate the stretch of highway which should be fenced (9970). The fence should be extended well past the crossing area to prevent end runs by ungulates. In Colorado, fence extensions of 800 m were recommended (140). Although effective for ungulates, these fences do not appear to be as effective at keeping carnivores off the right-of-way. For example, in Banff National Park, black bears obtain access to the right-of-way by climbing the fence and are killed on the TransCanada Highway (300, 951744, 951634). Similarly, coyotes gain access the TransCanada Highway and are killed frequently on the highway. Twenty-one of 24 coyote mortalities were road kills (951514). Although grizzly bears and cougars have not been killed within the fenced section of the TransCanada Highway, both species have gained access. Grizzly bears have dug under the fence on 2 occasions and 2 cougars have been recorded squeezing under the fence where it passed over rugged terrain (300). Florida has had better success keeping carnivores off highways with higher chain link fences. Cougars and black bear have been excluded from Interstate 75 and SR45 using a 3.4 m and a 3 m chain link fence, respectively, topped with 3 strands of barbed wire (950261, 19040).

Problems associated with fencing include the high initial cost (6820), and the labour and costs required to maintain the integrity of the fence (9960). These types of fence do not stop small animals from gaining access to the right-of-way and suffering mortalities on the road (e.g., 640, 9960, 19040, 70). Fencing the right-of-way of a highway also results in additional habitat loss along roadside verges since the fence is often placed outside of the right-of-way to reduce maintenance as a result of vehicular accidents and aesthetics (e.g., 640). One-way gates also must be included in fence design to facilitate the exit of animals that gain entry to the right-of-way. Design of functional one-way fences has been problematic and they also require regular checking and maintenance (e.g., 9960, 4900).

8.5 Culverts, Underpasses, and Overpasses

When disturbance corridors intersect existing wildlife travel routes, plans should include means to maintain connectivity between the habitat fragments on either side of the disturbance corridor. Since fences are often used to keep wildlife from entering highway rights-of-way and these fences are barriers to wildlife (see 8.4 above), methods to allow wildlife passage across the barrier are required. Culverts, underpasses, and overpasses, whether designed for wildlife or built to accommodate human needs, have been used by wildlife to cross these barriers safely.

Underpasses and culverts that were not originally designed for wildlife may be used by some species. Culverts that were designed for drainage and other human requirements have been used by wildlife as remnant corridors across both roads and high speed railways in Spain. These culverts are used by species as diverse as snakes, amphibians, small mammals, and carnivores including wild cats (*Felis sylvestris*), genets (*Genetta genetta*), Iberian lynx (*Lynx pardina*) and red fox (*Vulpes vulpes*) (951674, 14710). Storm drain culverts are used by tortoises (*Gopherus agassizii*) and other small vertebrates to pass under highway in the western Mojave Desert in California (120, 18950). In Banff National Park, 3 bridges built primarily as watercourse bridges and over a railway overpass allowed ungulates to cross over the fenced TransCanada Highway (10060). A grizzly bear has also used an underpass containing Highway 1A, the railway, and the Bow River to cross under the TransCanada Highway (300). However, not all existing underpasses are used by wildlife. Eight bridge-type underpasses not designed for use by deer (including 3 near major deer crossings) on an interstate highway in Idaho received very little use by deer even though the highway cut across a migration route (6310).

Passages designed for wildlife have been used in many locations to allow travel routes across barriers created by fenced roads. In Florida, cougars and black bears were the target species for underpasses constructed on Interstate 75 and SR45 and both species have used the structures (19040, 70, 950093). Many other wildlife species have also used these crossing structures including white-tailed deer, bobcats, and raccoons (*Procyon lotor*). Eight wildlife underpasses designed for ungulates along the TransCanada Highway have been successful for those species, although the small moose population in the Bow Valley has not made frequent use of them (18900). The same cannot be said for many carnivores in the Bow Valley (300, 280). Black bear use is occasional, grizzly bears almost never use them, cougars didn't use them immediately following construction in 1983-1988 but were using them by 1994, and wolf use of underpasses is inconsistent. Some individuals and packs moved freely through the underpasses while others did not. A highway underpass designed for moose in Alaska worked (670). Two mountain goat underpasses in Glacier National Park were also successful. After reconstruction of U.S. Highway 2 in Glacier National Park, 1,204 (99.6%) of 1,209 instances of mountain goats crossing the highway were under either of the 2 bridges (9310). Underpasses designed for deer have also been generally successful (e.g., 650, 140, 6050). Overpasses have not been used to the same degree in North America as underpasses. However, use of 11 "green bridges" (varying in width from 8 m to 200 m) by wildlife are being studied in Europe and the results are promising (19080). Deer, badgers, foxes, marten, and common hare were documented using these large landscape bridges, while among large mammals present in the areas, only wild boar had not used the overpasses. Two studies on ungulates, 1 from the U.S. and 1 from Europe reported that underpasses were preferred to overpasses for the species considered (140, 9800).

What makes a crossing structure across a disturbance corridor work? In virtually all studies of underpasses, overpasses, and culverts, the most important factor was the location of the crossing structure relative to wildlife use in the surrounding matrix. If the structure was located where wildlife movement routes naturally occured across the disturbance corridor, the structure was used (e.g., mountain goats [9300], deer [650], cougar [18990, 951044], black bears [19040]). Thus, ideal locations for crossing structures were to some degree species-specific. However, experience has shown that structures used by target species are also used extensively by many other species of wildlife (e.g., 19040, 70). Similarly, culverts under a high speed rail link were used more frequently in scrubland than in border habitats and farmland (951674). Other factors which were deemed important included vegetation and cover attributes (951674, 14710, 951114), physical dimensions (e.g., small mammals [951674], small vertebrates [14710], cougars [951114], large mammals [15850], black bears [19040], deer [140], mountain goat [9300]), and a lack of human disturbance in the vicinity (e.g., 9310, 951674, 951114).

The success of a crossing structure through a disturbance corridor cannot be determined in a short time after construction. There may be a gradual learning process that occurs with the use of these crossing structures (e.g., 690). Cougar use of underpasses on the TransCanada Highway in Banff National Park and along Interstate 75 in Florida has increased over time (300, 950261). Although certain species of wildlife may not use a crossing structure immediately, over time they may learn. This is most likely the case with long-lived species with large home ranges like grizzly bears and wolverines.

8.6 Collisions with Powerlines and Electrocutions

Collisions with powerlines can be reduced in 2 ways. First, powerlines may be located to minimize the likelihood of collisions (see 8.2 above). The second way involves design modifications of powerlines themselves. Bevanger (16140) presents a very detailed review of the subject and this summary draws extensively from it unless noted otherwise.

Design modifications are meant to change the configuration of the powerlines and poles to reduce the likelihood of collisions. Lines that are situated continuously below tree top level through a forested area greatly reduces the probability of collisions since most birds fly above the tops of the trees in a forest. Arrays of powerlines that are horizontal are better than vertical or other configurations because birds are vulnerable to collisions at just 1 flying height when a flat configuration is used. Powerlines should be grouped in a common corridor where possible so that they occupy a smaller area, again reducing the probability of collisions. In addition to occupying less space, bundled cables are more visible. Removing ground wires or modifying grounding methods may also reduce collision frequency. Increasing the visibility of the powerlines also appears to reduce bird collisions with wires. Marking devices include wire coating, physical enlargement, predator silhouettes, acoustical scaring devices, and the use of light.

Testing the usefulness of many of these methods is required, although effective assessment is difficult (16140). The ability of yellow spiral vibration dampers and yellow fiberglass swinging plates to reduce collision frequency has been tested in Colorado (18450). Both marker types significantly reduced mortality. Birds reacted to marked lines at greater distances and increased their altitude as compared to unmarked lines. Factors affecting collisions or marker effectiveness included wind, nocturnal flights, and disturbance. However, plates damaged distribution lines, precluding their continued use. In another line marking experiment, an attempt was made to direct mergansers (*Mergus merganser*) away from the lines by obstructing key flight paths with 1.7-m diameter, helium-filled balloons placed at transmission line height (990). Obstruction of flight paths caused significant shifts in merganser flight patterns that resulted in a reduction of documented mortality from 41 fatal collisions when balloons were absent to none when balloons were present.

Bird electrocutions occur whenever a bird touches 2 conductors or a conductor and a ground wire at the same time (16140). Bird electrocutions occur because support structures for transmission lines are attractive perching platforms for resting, roosting, and hunting (e.g., 15680, 8050, 16060, 12142, 4982). In addition, they are used by many species, particularly raptors, as supports for nests (18120, 15680, 16040). Bevanger (16140) also reviewed mitigation measures for bird electrocution. Removal of grounding wires, the modification of grounding methods, modifications to the configuration of lines, insulated cabling, and support pylon modifications are areas where improvements could be realized. The main modifications of poles, pylons, and towers include insulation of conductors in the immediate vicinity of supports, elevated perch constructions, perching guards, and lowering or extending cross-arms and pole tops to increase the distances between wires. Hanging insulators are better than top-mounted insulators since there is no phase conductor on top of the cross-arm. Since certain support structures are often preferred by birds, these modifications can be focused on these problem structures (19710). Since electrocution problems are often species-specific in an area, modifications should be directed to the target bird species (16140).

8.7 Other Mitigation Measures

Many other mitigation measures have been developed in attempts to reduce the disturbance of wildlife as a result of development corridors. Most are associated with attempting to reduce the frequency of vehicle collisions on highways. Optical game warning devices such as Swareflex reflectors have been shown to be largely ineffective (650, 18100), although other studies have claimed that they can be effective in certain circumstances (e.g., 9800, 8350). Similarly, warning whistles are likely ineffective in most cases (650). Deer guards, similar in design to cattle guards have been tested and none were especially effective (140, 8740). Nearly all U.S. states use some combination of signs, modified speed limits, habitat alteration, and education programs, in addition to the mitigation techniques already described, to attempt to reduce collisions between deer and vehicles (650). However, Romin and Bissonette (650) reported that few state agencies have evaluated the success of these techniques.

In a recent review of ungulate traffic accidents in Europe (18860), seasonal use of intermittently lighted warning signs, triggered if possible by the ungulates on the road, was recommended for secondary roads where traffic volumes did not warrant fencing and underpasses or overpasses. A crosswalk for deer is currently being tested in Utah (18920). The crosswalk system is used in conjunction with right-of-way fencing to funnel deer attempting to cross the highway to specific well-marked areas where motorists can anticipate them. The crosswalk eliminates the need for expensive underpasses or overpasses. A 40% reduction in deer-vehicle collisions was documented (18920). Design changes and further testing of the crosswalk system is required.

Appendix 1. Common and Latin names of wildlife referred to in text.

Birds

American kestrel	*Falco sparverius*
bald eagle	*Haliaeetus leucocephalus*
barn owl	*Tyto alba*
black duck	*Anas rubripes*
black-throated green warbler	*Dendroica virens*
blackpoll warbler	*Dendroica striata*
blue-winged teal	*Anas discors*
boreal owl	*Aegolius funereus*
Brewer's blackbird	*Euphagus cyanocephalus*
brown creeper	*Certhia americana*
brown-headed cowbird	*Molothrus ater*
burrowing owl	*Athene cunicularia*
Canada goose	*Branta canadensis*
common raven	*Corvus corax*
Cooper's hawk	*Accipiter cooperii*
double-crested cormorant	*Phalacrocorax auritus*
eastern screech owl	*Otus asio*
eider duck	*Somateria mollissima*
ferruginous hawk	*Buteo regalis*
golden eagle	*Aquila chrysaetos*
golden-crowned kinglet	*Regulus satrapa*
goshawk	*Accipiter gentilis*
gray partridge	*Perdix perdix*
great blue heron	*Ardea herodias*
gyrfalcon	*Falco rusticolis*
harlequin duck	*Histrionicus histrionicus*
hermit thrush	*Catharus guttatus*
least flycatcher	*Empidonax minimus*
marsh harrier	*Circus cyaneus*
meadowlark	*Sturnella neglecta*
merlin	*Falco columbarius*
northern saw-whet owl	*Aegolius acadicus*
northern spotted owl	*Strix occidentalis*
osprey	*Pandion haliaetus*
ovenbird	*Seiurus aurocapillus*
peregrine falcon	*Falco peregrinus*
pied-billed grebe	*Podilymbus podiceps*

pine siskins	*Carduelis pinus*
pink-footed goose	*Anser brachyrhynchus*
piping plover	*Charadrius melodus*
prairie falcon	*Falco mexicanus*,
ptarmigan	*Lagopus* species
red-eyed vireo	*Vireo olivaceous*
red-shouldered hawk	*Buteo lineatus*
red-tailed hawk	*Buteo jamaicensis*
red-winged blackbird	*Agelaius phoeniceus*
ring-necked pheasant	*Phasianus colchicus*
rough-legged hawk	*Buteo lagopus*
ruffed grouse	*Bonasa umbellus*
sharp-tailed grouse	*Tympanuchus phasianellus*
Spanish imperial eagle	*Aquila adalberti*
Swainson's hawk	*Buteo swainsoni*
Swainson's thrush	*Catharus ustulatus*
trumpeter swan	*Olor buccinator*
tundra swan	*Olor columbianus*
willow warbler	*Phylloscopus trochilus*
wood thrush	*Hylocichla mustelina*

Mammals

american marten	*Martes americana*
badger	*Meles meles*
barren-ground caribou	*Rangifer tarandus granti*
black bear	*Ursus americanus*
bobcat	*Lynx rufus*
California bighorn sheep	*Ovis canadensis californiana*
cougar	*Puma concolor*
coyote	*Canis latrans*
Dall's sheep	*Ovis dalli*
deer mouse	*Peromyscus maniculatis*
desert bighorn sheep	*Ovis canadensis nelsoni*
elk	*Cervus elaphus*
European lynx	*Lynx lynx*
fisher	*Martes pennanti*
grizzly bear	*Ursus arctos*
Iberian lynx	*Lynx pardina*
long-tailed weasel	*Mustela frenata*
lynx	*Lynx canadensis*

mink	*Mustela vison*
moose	*Alces alces*
mountain goat	*Oreamnos americanus*
mule deer	*Odocoileus hemionus*
red fox	*Vulpes vulpes*
river otter	*Lutra canadensis*
Rocky Mountain bighorn sheep	*Ovis canadensis canadensis*
white-tailed deer	*Odocoileus virginianus*
wolf	*Canis lupus*
wolverine	*Gulo gulo*
woodland and mountain caribou	*Rangifer tarandus caribou*

Appendix 2. Personal Communications

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